Welcome to
NASA Applied Remote Sensing Training Program (ARSET) Webinar Series

Introduction to Remote Sensing of Snow Properties

Course Dates: Every Tuesday, January 16 – 6 February 2013

ARSET

Applied **R**emote **SE**nsing **T**raining

A project of NASA Applied Sciences

NASA Earth Science Applied Sciences Program

Applications to Decision Making: Eight Thematic Areas

Agricultural Efficiency

Air Quality

Climate

Disaster Management

Ecological Forecasting

Public Health

Water Resources

Weather (Aviation)

Who Can Benefit from ARSET Courses?

- **Public Sector:** Local, state, federal, international regulatory agencies, project managers, health and disaster management agencies, World Bank, United Nations
- **Private Sector:** industry, NGOs, consultants, and other organizations involved in capacity building
- **Scientists/Technical Experts**: Meteorologists, Modelers, Hydrologists, Agriculture, Health and Disaster Researchers

Applied Remote Sensing Training (ARSET)

Professional courses on remote sensing applications

31 courses to date

Water Resources and Disaster Management
http://water.gsfc.nasa.gov

Air Quality (since 2008)
http://airquality.gsfc.nasa.gov

Online courses:

- Required for hands-on courses
- For managers and technical staff

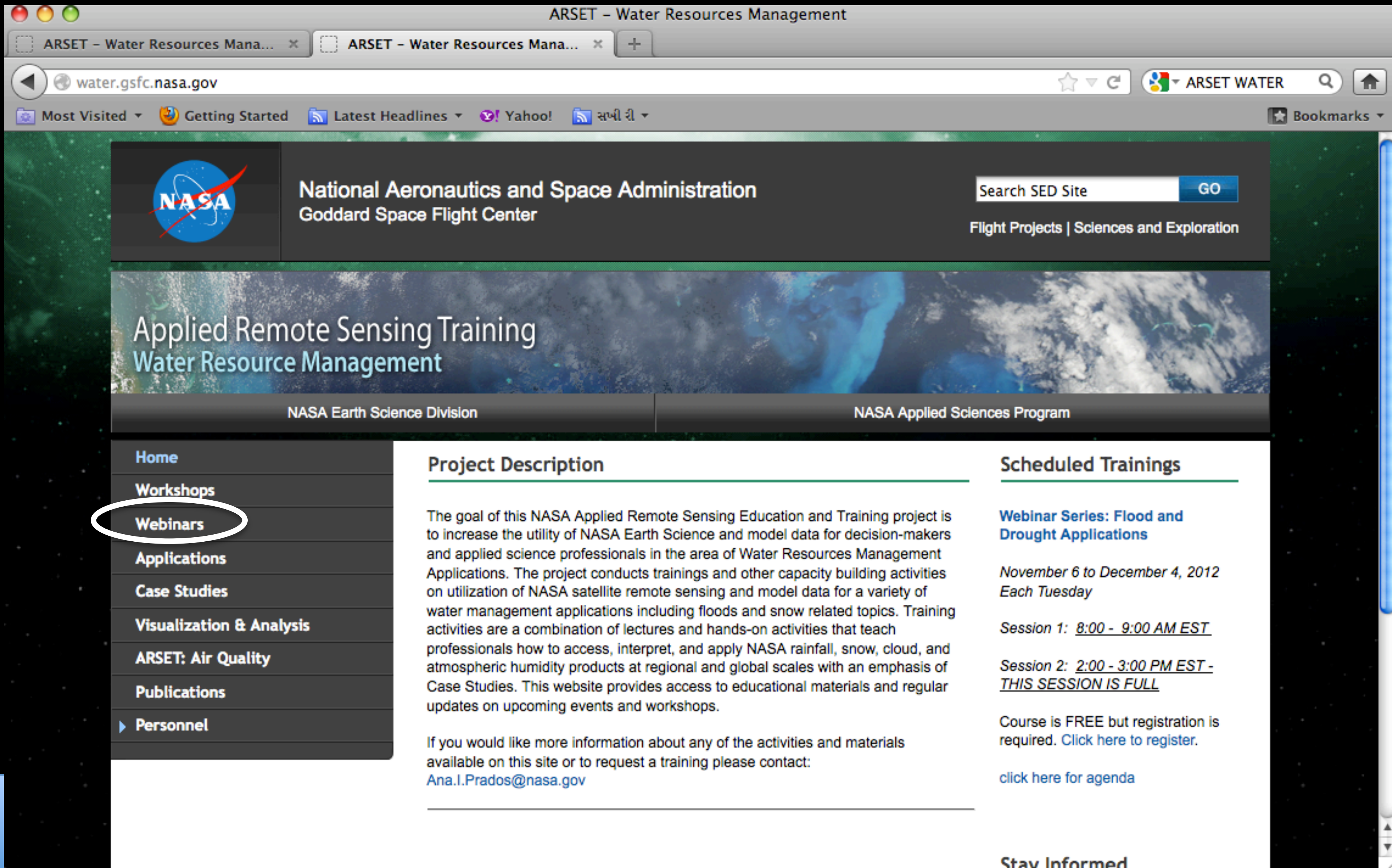
Hands-on courses:

- More technical
- Basic or advanced

ARSET works directly with agencies in the public and private sectors

ARSET Water Resource Management

http://water.gsfc.nasa.gov/



Course Structure

- One lecture per week – every Tuesday between 16 January to 6 February
  16 January (2- 3 PM Eastern Time/11 AM – noon PST)
  23 January (2- 3 PM Eastern Time)
  30 January (2- 3 PM Eastern Time)
  6 February ((2- 3 PM Eastern Time)

- Presentations of all webinars can be found on:
  http://water.gsfc.nasa.gov/webinars/

- Week-4 webinar by Tom Painter and Chris Mattmann from NASA/JPL

- Q/A sessions: 23 January (3- 3:15 PM Eastern Time)
  30 January (3- 3:15 PM Eastern Time)
  6 February (3- 3:15 PM Eastern Time)

- 'Chat Window' and call-in number for Q/A during webinars

NASA Snow Products Training Overview

- *To provide a physical background for understanding the new directions in optical remote sensing and cryospheric/hydrologic sciences.*
- *To describe the MODSCAG fractional snow cover products.*
- *To describe the MODDRFS dust radiative forcing in snow products.*
- *To describe the Snow Data Server and data availability*
- *Ultimately to provide hands-on experience with these products in follow-on in-person courses.*

Introductions

Thomas H. Painter

PhD, Geography UC-Santa Barbara

BS, Mathematics, Colorado State U.

Developed cutting edge remote sensing retrievals from multispectral and hyperspectral optical sensors.

Developed our understanding of dust radiative forcing on snowmelt and runoff in mountain systems.

AGU President Cryosphere Focus Group

Introductions

Christian Mattmann

PhD, University of Southern California

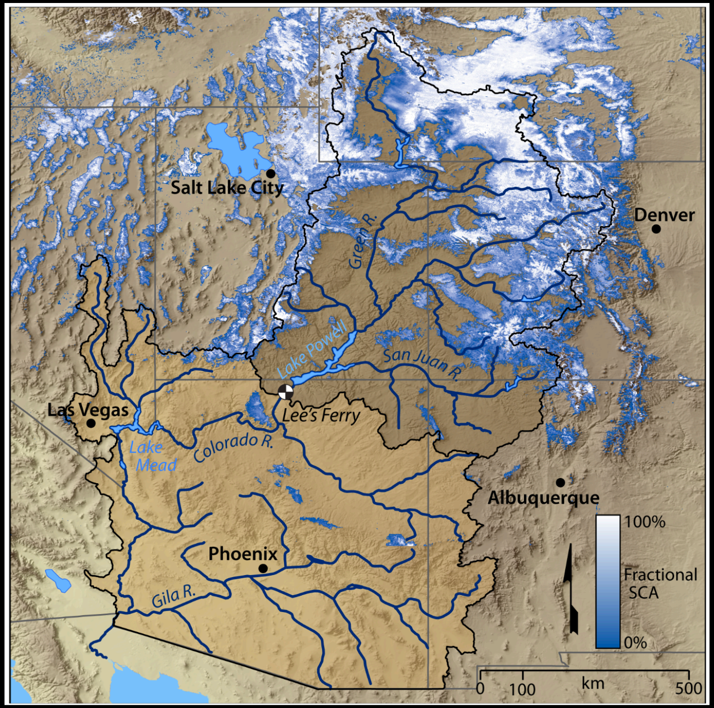
BS, USC

Senior Computer Scientist, Jet Propulsion Laboratory

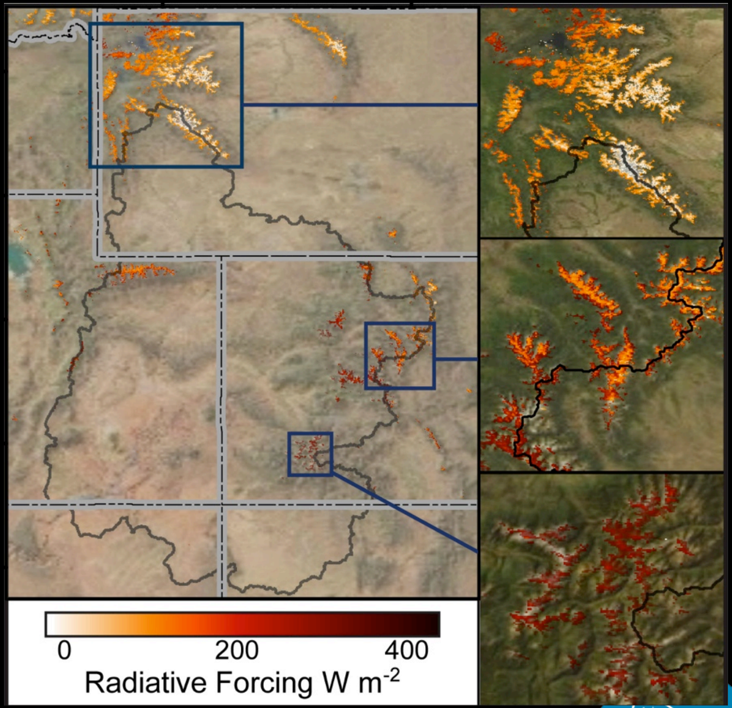
Software Architecture/Engineering Professor, University of Southern California

JPL Remote Sensing of Snow

MODIS Snow Covered Area and Grain size (MODSCAG)

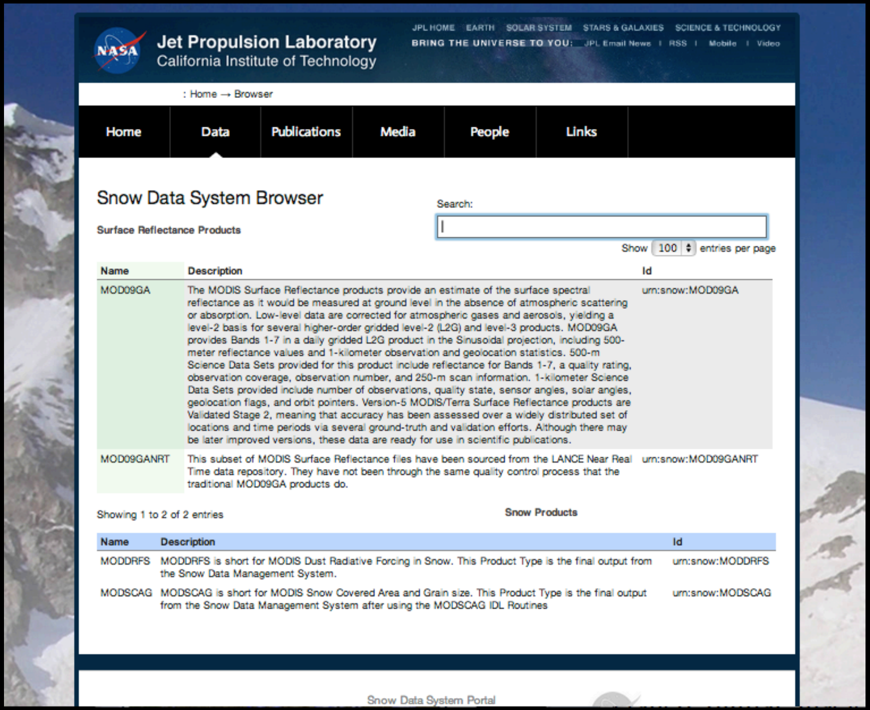


MODIS Dust Radiative Forcing in Snow (MODDRFS)

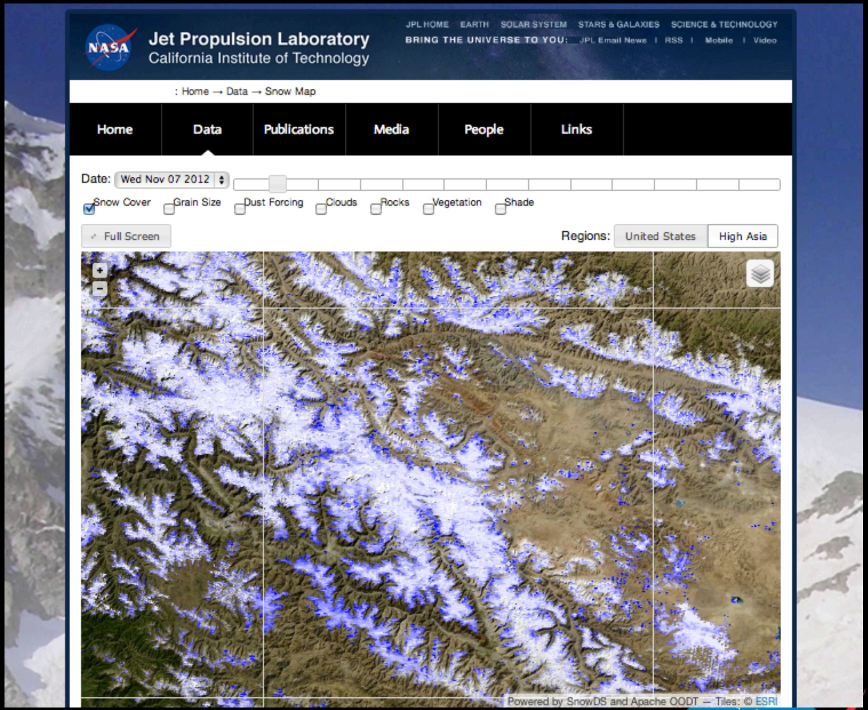


JPL Remote Sensing of Snow

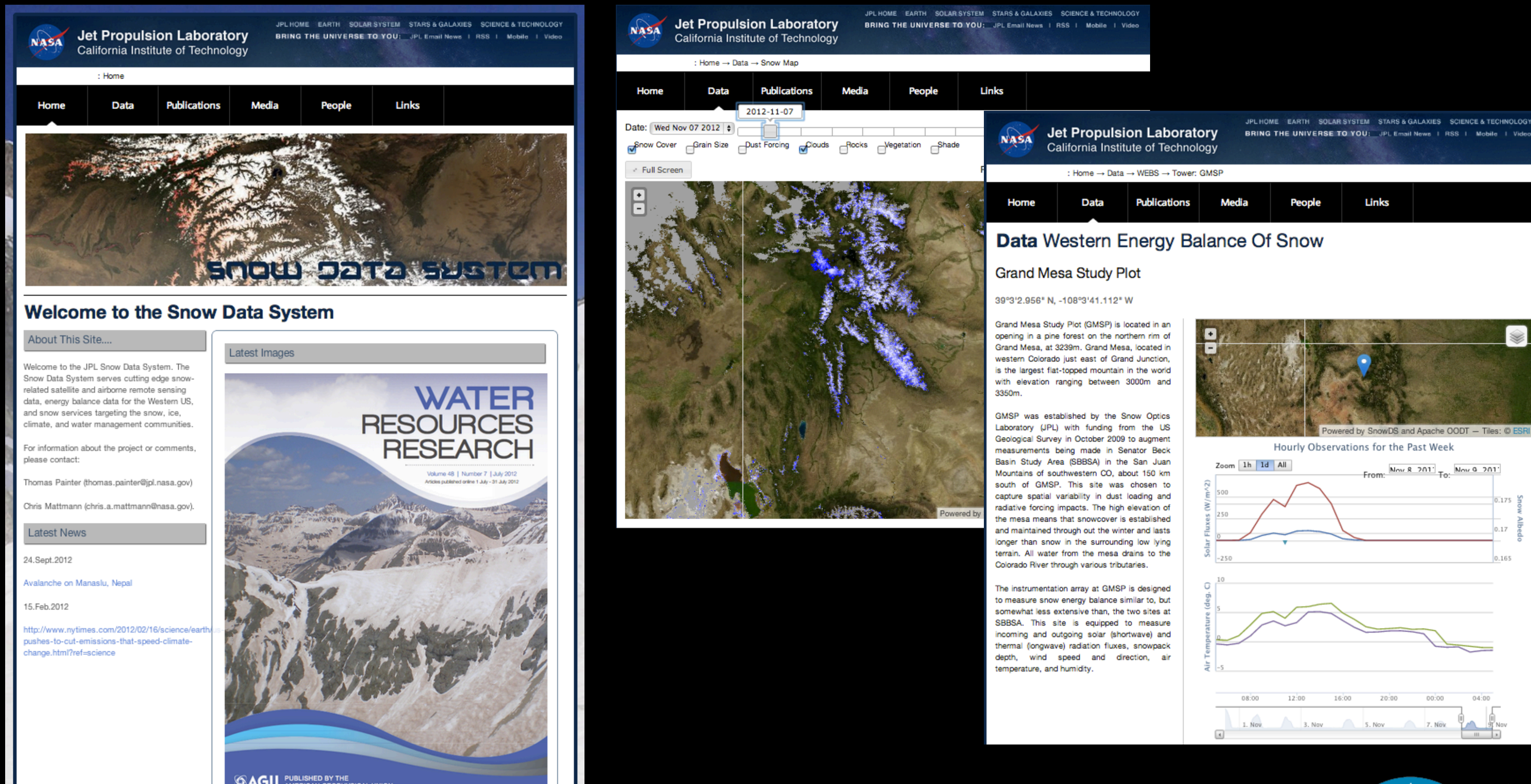
MODIS historical processing



MODIS Near Real Time (NRT) processing



JPL Snow Data Server



http://snow.jpl.nasa.gov/

MODSCAG

Remote Sensing of Environment 113 (2009) 868–879

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Retrieval of subpixel snow covered area, grain size, and albedo from MODIS

Thomas H. Painter [a,*], Karl Rittger [b], Ceretha McKenzie [c], Peter Slaughter [b], Robert E. Davis [c], Jeff Dozier [b]

[a] Department of Geography, University of Utah, Salt Lake City, UT 84112, USA
[b] Donald Bren School of Environmental Science and Management, University of California, Santa Barbara, CA 93106, USA
[c] US Army Cold Regions Research and Engineering Laboratory, Hanover, NH 03755, USA

MODSCAG

Advances in Water Resources xxx (2012) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Advances in Water Resources

journal homepage: www.elsevier.com/locate/advwatres

ELSEVIER

Assessment of methods for mapping snow cover from MODIS

Karl Rittger [a], Thomas H. Painter [b], Jeff Dozier [a,*]

[a] Bren School of Environmental Science & Management, University of California, Santa Barbara, CA 93106-5131, United States
[b] Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109, United States

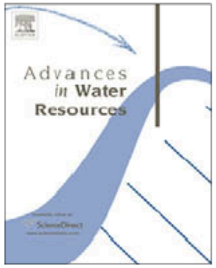
MODSCAG

Advances in Water Resources 31 (2008) 1515–1526

Contents lists available at ScienceDirect

Advances in Water Resources

journal homepage: www.elsevier.com/locate/advwatres



Time–space continuity of daily maps of fractional snow cover and albedo from MODIS

Jeff Dozier [a,*], Thomas H. Painter [b], Karl Rittger [a], James E. Frew [a]

[a] *Donald Bren School of Environmental Science and Management, University of California, Santa Barbara, CA 93106-5131, United States*
[b] *Department of Geography, University of Utah, Salt Lake City, UT 84112, United States*

MODDRFS

GEOPHYSICAL RESEARCH LETTERS, VOL. 39, L17502, doi:10.1029/2012GL052457, 2012

Radiative forcing by light absorbing impurities in snow from MODIS surface reflectance data

Thomas H. Painter,[1] Ann C. Bryant,[2] and S. McKenzie Skiles[3]

Received 18 June 2012; revised 18 July 2012; accepted 23 July 2012; published 11 September 2012.

Training overview

- Remote sensing foundations
- MODSCAG
- MODDRFS
- SnowMap utilities

Remote Sensing Foundations

Thomas H. Painter, Chris Mattmann
NASA Jet Propulsion Laboratory
California Institute of Technology

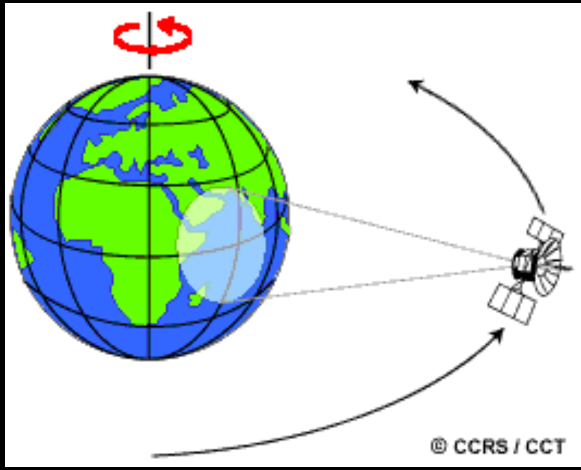
Outline

1 Satellite Foundations
2 Sun-Atmosphere-Earth Interactions
3 Snow Hydrology
4 Snow Optical Properties
5 Snow Reflectance

SATELLITE FOUNDATIONS

Types of satellite orbits

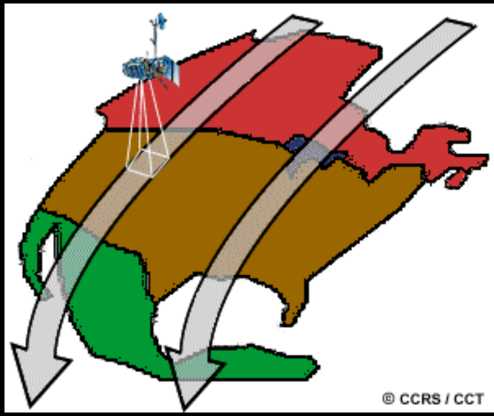
Geostationary orbit



- Fixed above earth at ~36,000 km
- Frequent Measurements
- Limited Spatial Coverage

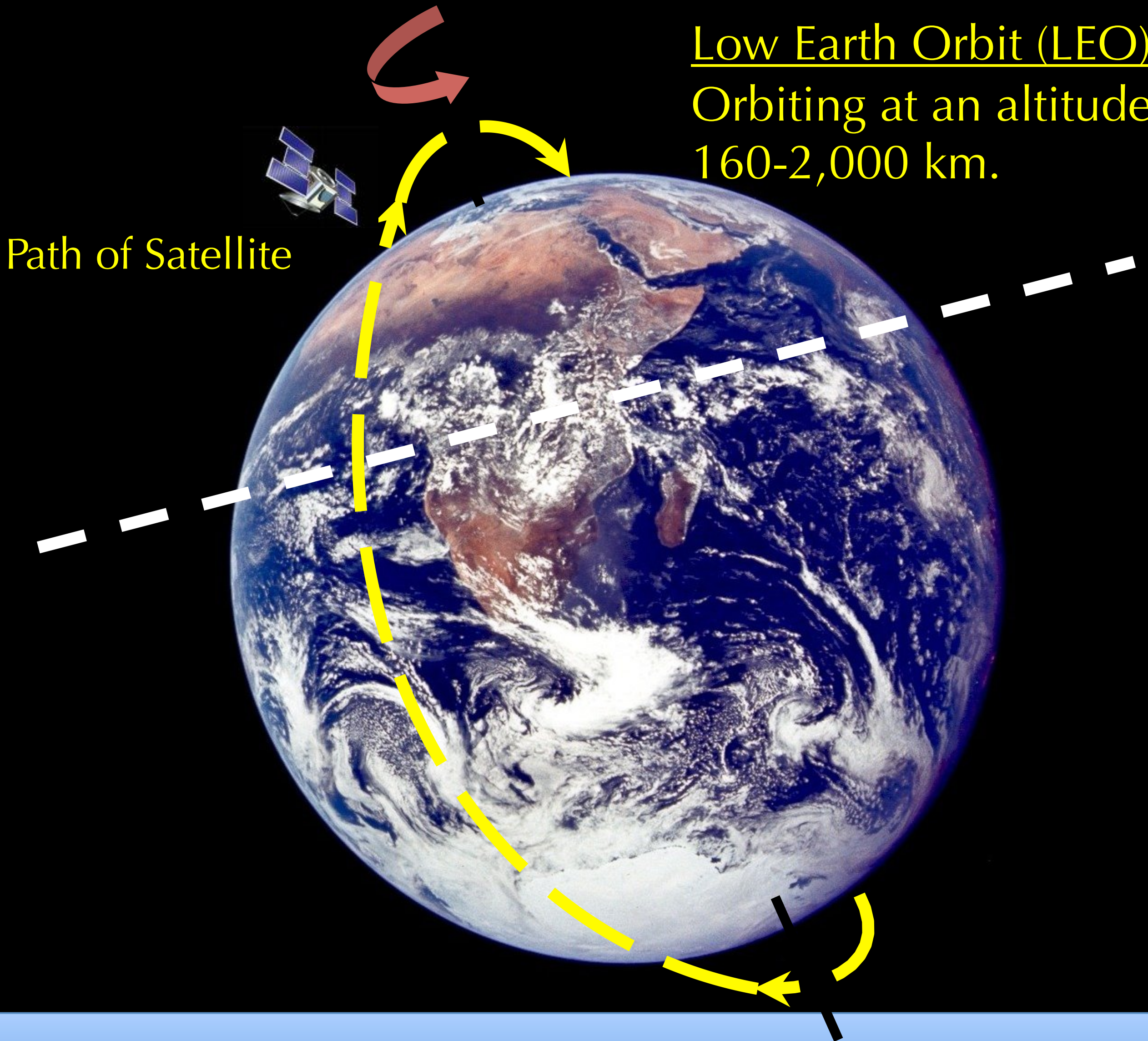
Low Earth Orbit (LEO)

- **Polar (Terra)**
- **Nonpolar (TRMM)**



- Circular orbit constantly moving relative to the Earth at 160-2000 km
- Less Frequent measurements (< 2 times per day)
- Large (global) spatial coverage
- Better spatial resolution

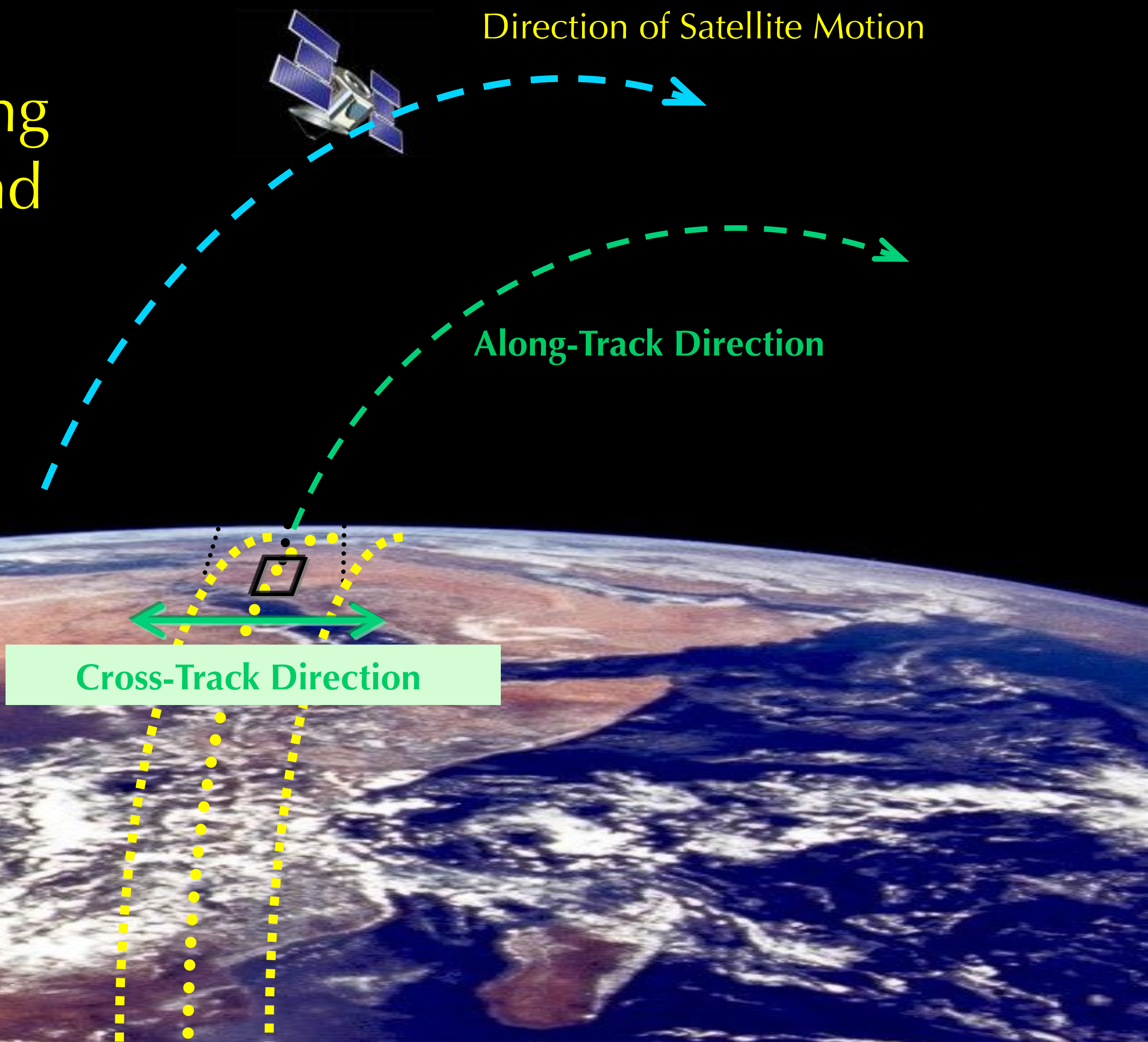
Low-Earth Orbits (LEO)



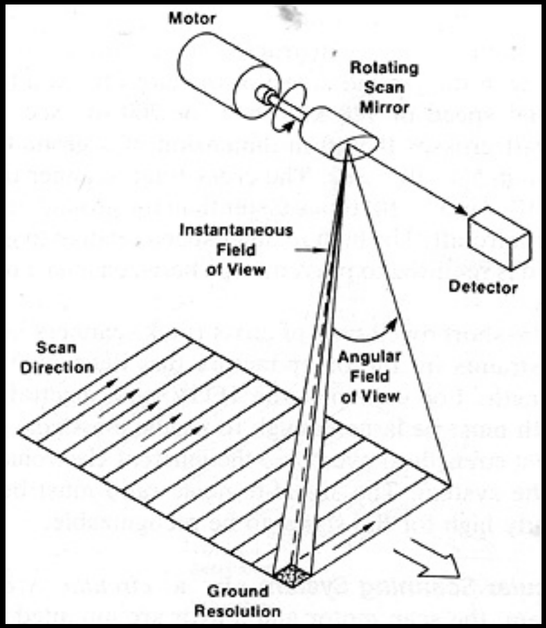
Low Earth Orbit (LEO): Orbiting at an altitude of 160-2,000 km.

LEO Field-of-View (FOV)

The orbit is defined as having a **cross-track** and an **along-track** direction.



Earth-Observing Satellites

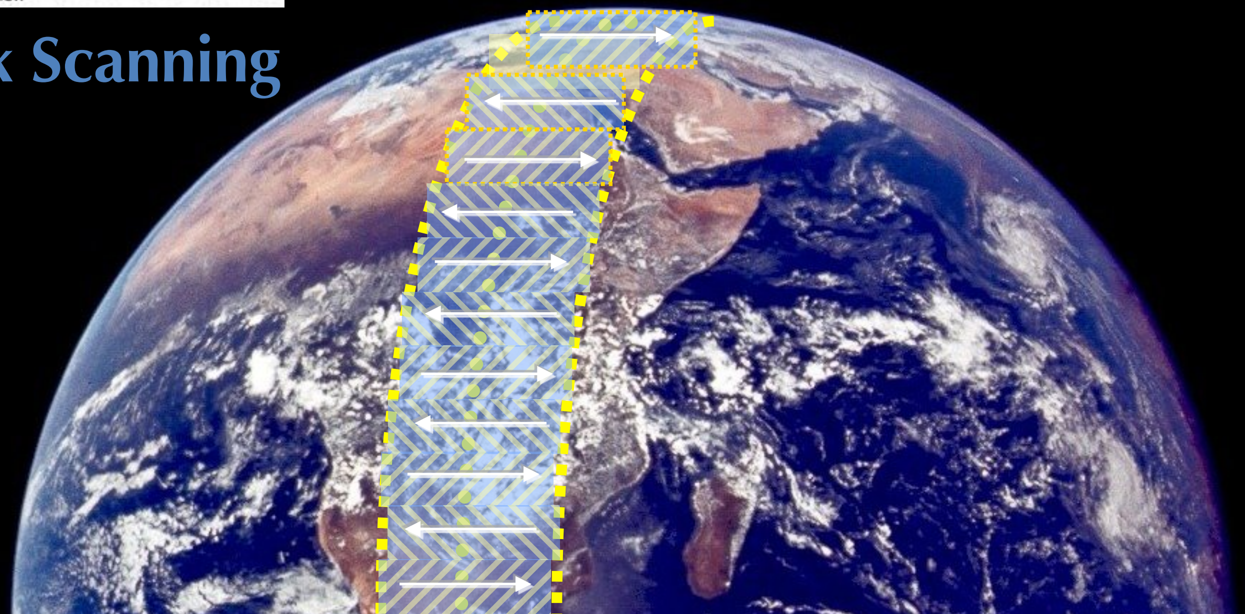


Cross-Track Scanning

Direction of Satellite Motion

"Cross-Track Scanning," Scan mirror swings back and forth.

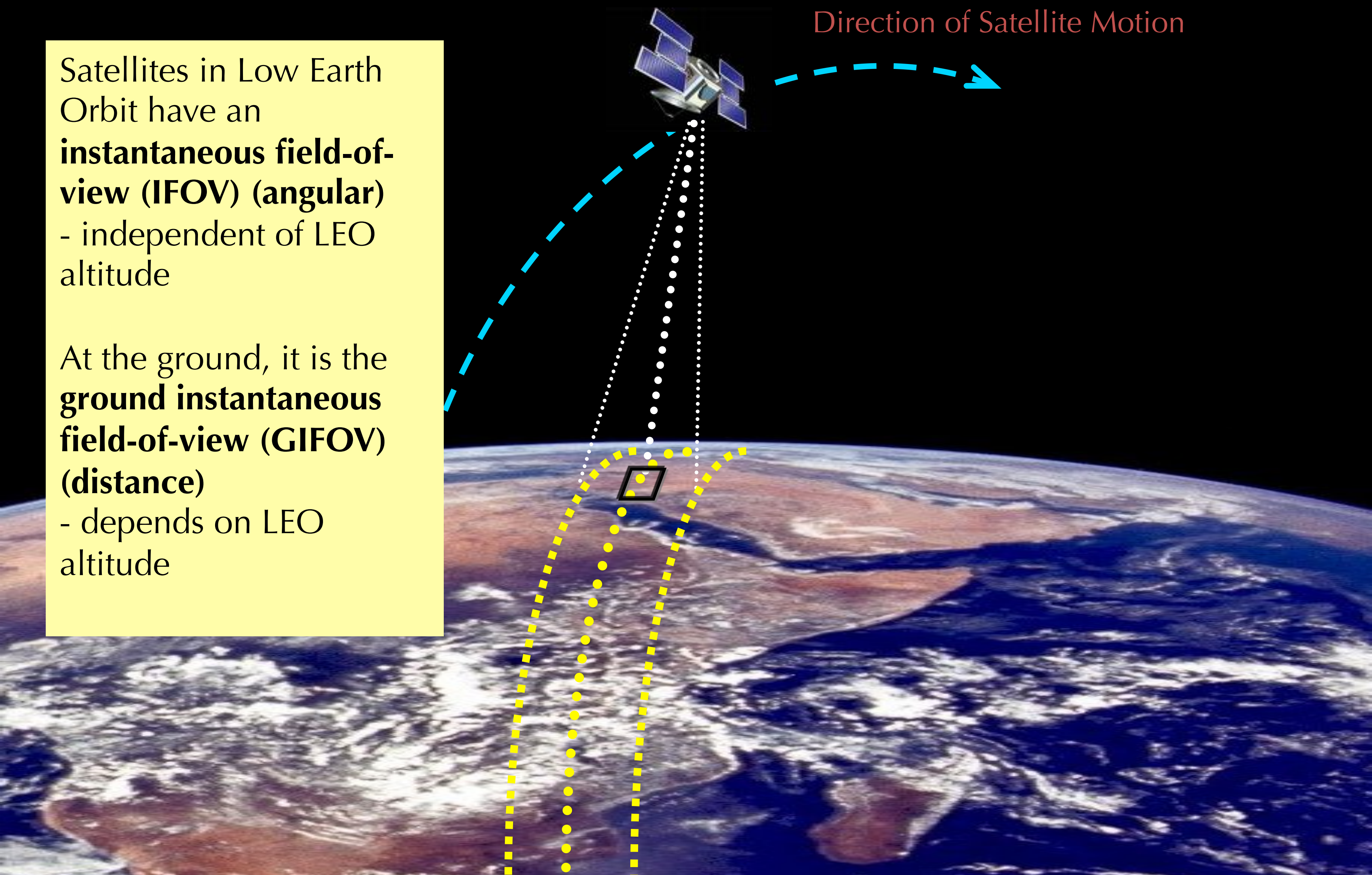
Sensor observes pixels in sequence across track and along the direction of the satellite's motion.



LEO Field-of-View (FOV)

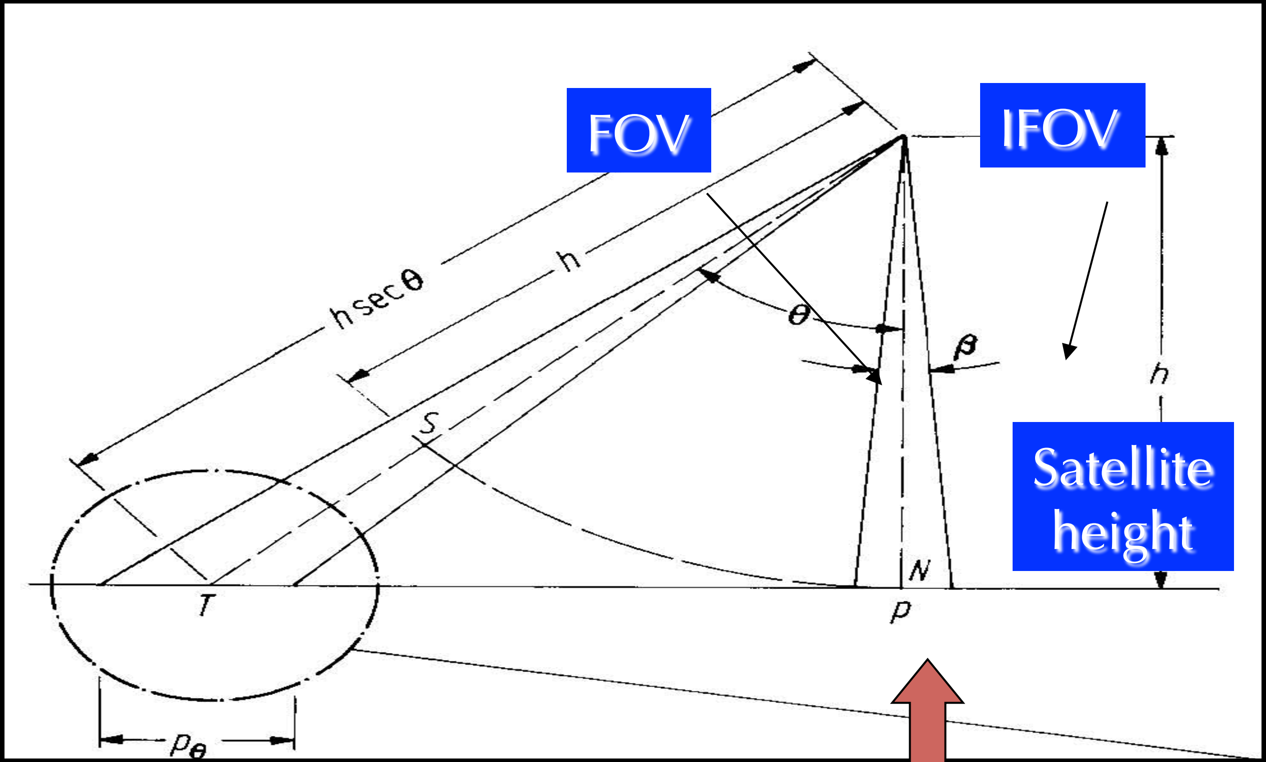
Satellites in Low Earth Orbit have an **instantaneous field-of-view (IFOV) (angular)**
- independent of LEO altitude

At the ground, it is the **ground instantaneous field-of-view (GIFOV) (distance)**
- depends on LEO altitude



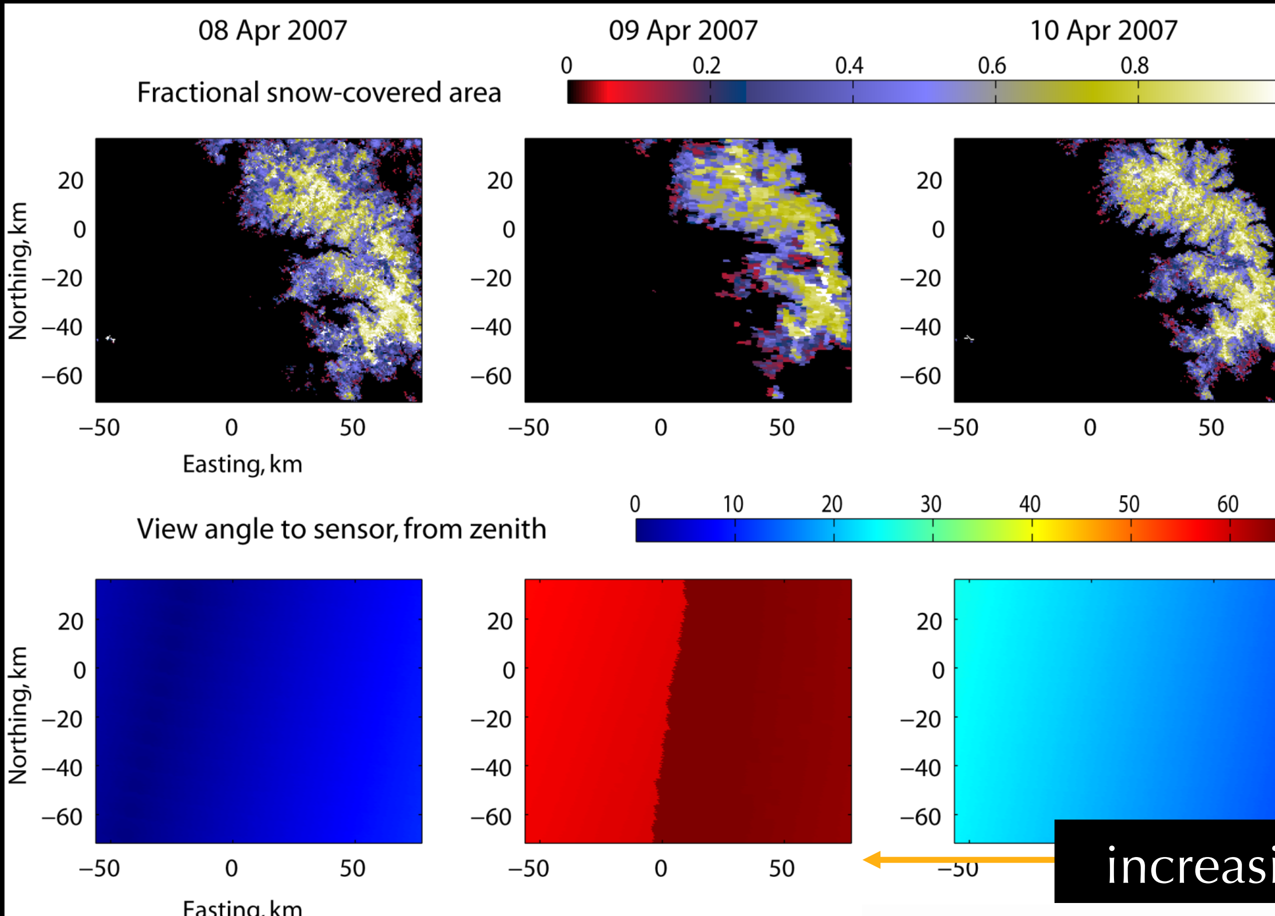
Spatial Resolution

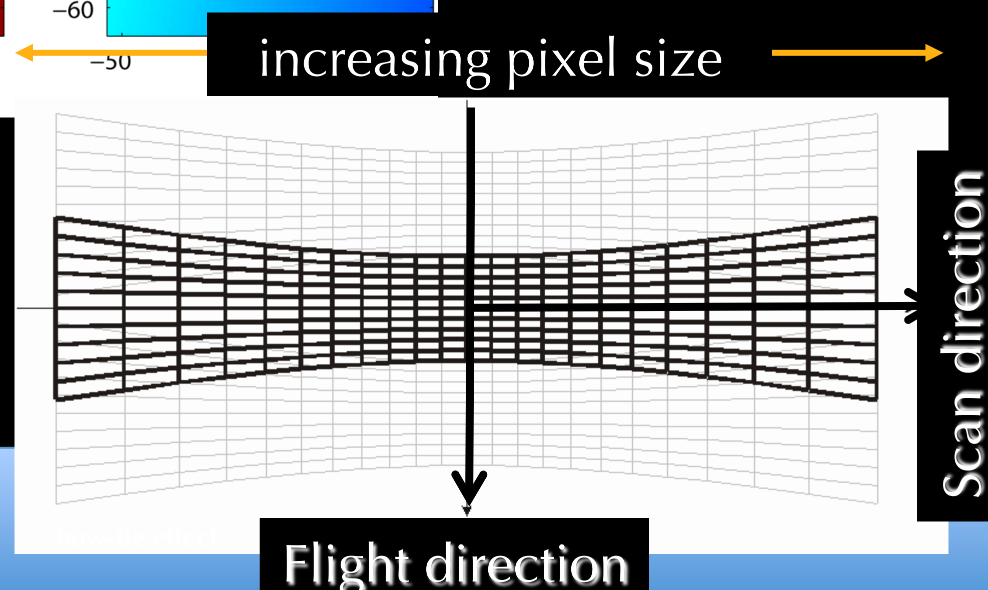
- Spatial Resolution : A simple definition is the pixel size that satellite images cover.
- Satellite images are organized in rows and column called raster imagery and each pixel has a certain spatial resolution.



GIFOV
(off-nadir pixel size)

GIFOV
(pixel size)


08 Apr 2007
09 Apr 2007
10 Apr 2007
Fractional snow-covered area
0 0.2 0.4 0.6 0.8 1
Northing, km
20 0 −20 −40 −60
−50 0 50
Easting, km
View angle to sensor, from zenith
0 10 20 30 40 50 60


increasing pixel size
Scan direction
Flight direction

Temporal Resolution of Remote Sensing Data

The frequency at which data are obtained is determined by:

- Type and height of orbit
- Size of measurement swath

Temporal resolution of Polar Orbiting Satellites
Example: Terra, Aqua

- Observations available only **at the time of the satellite overpass.**
- IR based observations available 2X a day
- Visible observations available 1X a day
- Polar regions may have several observations per day.

Remote Sensing – Resolutions

Spectral resolution – The number and range of spectral bands.

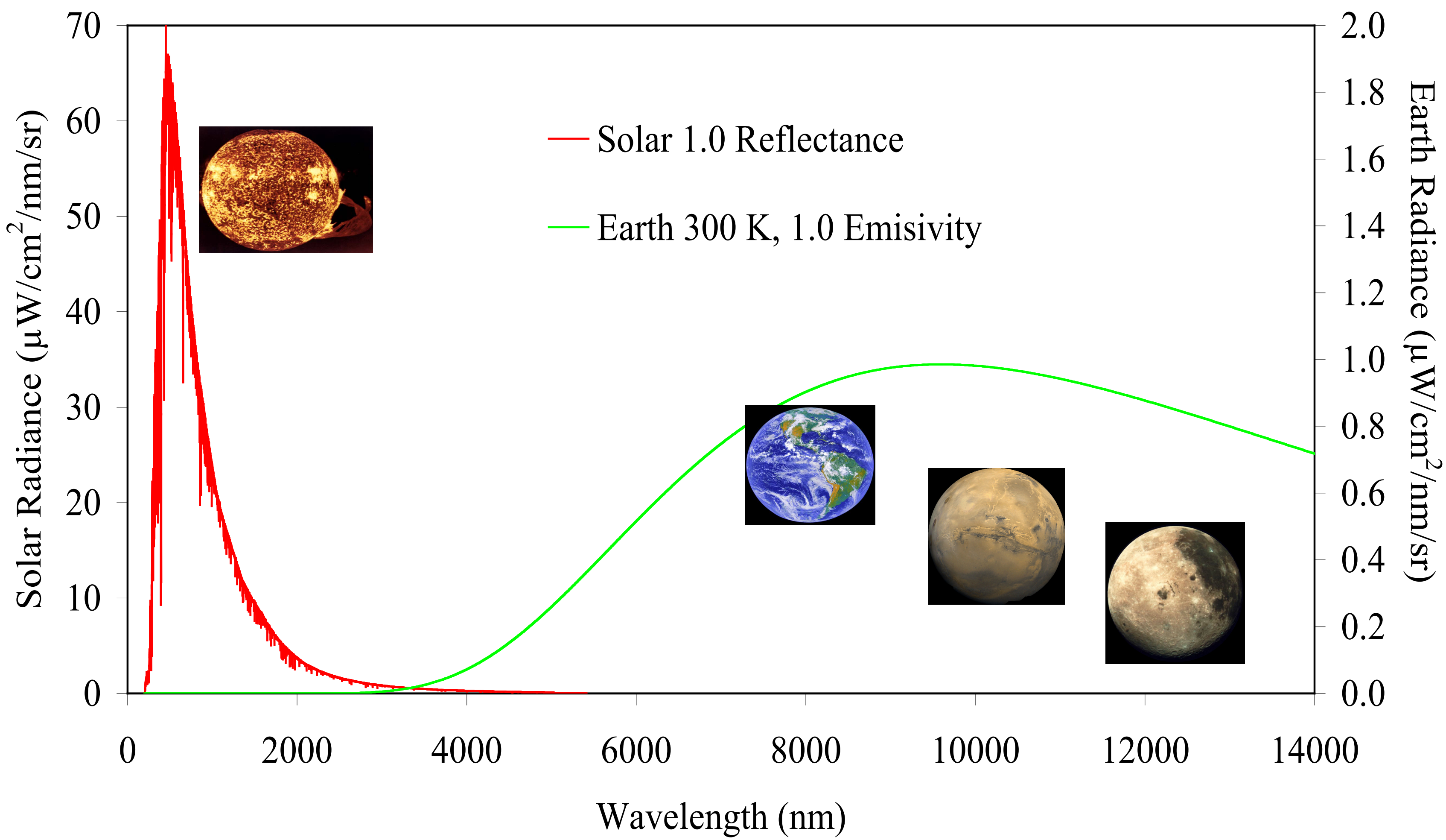
More bands = More information

Radiometric resolution – The bandwidth of the individual spectral bands. Important for avoiding or taking advantage of "atmospheric windows"

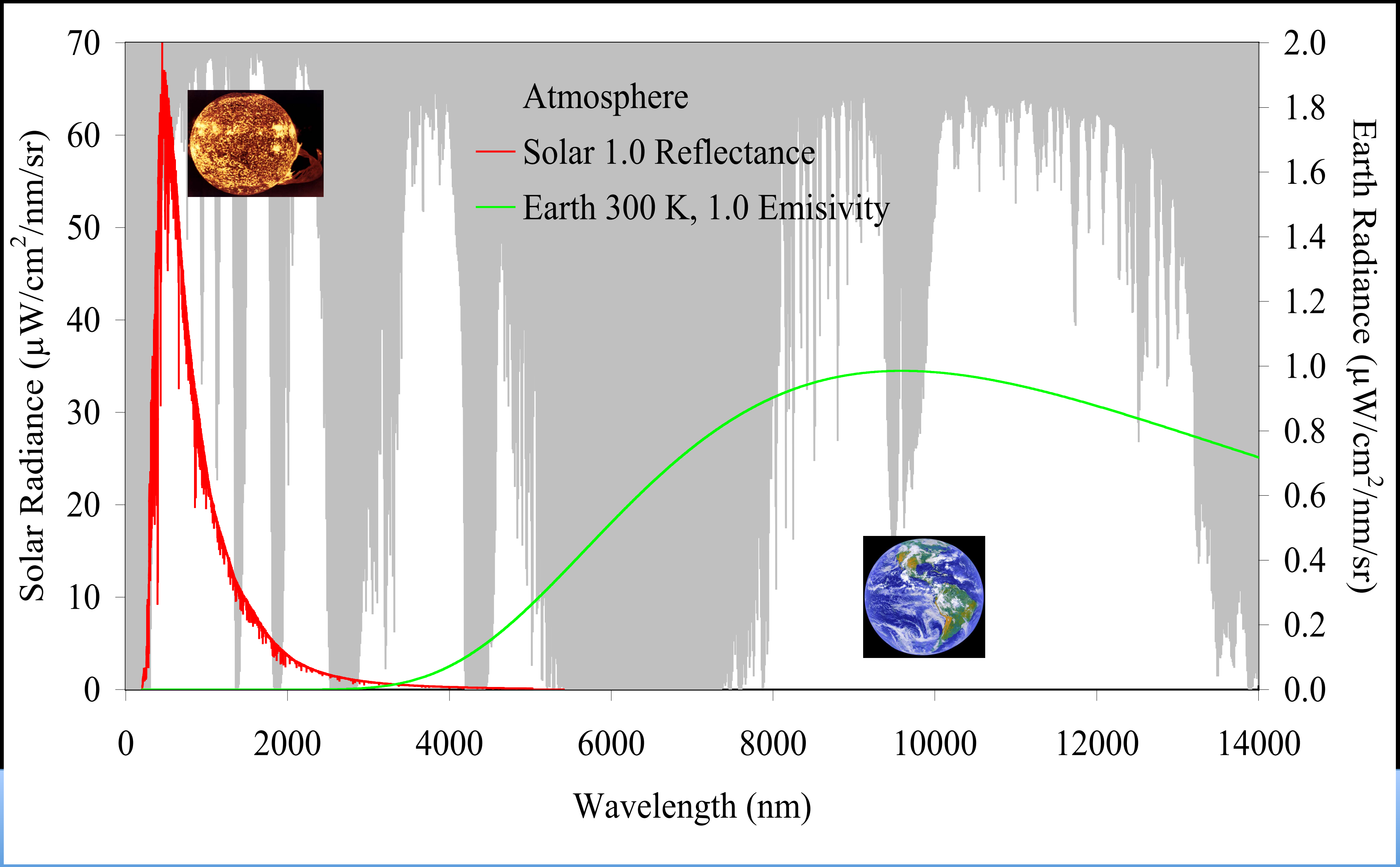
Spectral dynamic range – The range of radiances in which change in radiance can be detected. This is critical for snow in particular because with many sensors (e.g. Landsat Thematic Mapper), snow's reflected radiance saturates the sensor's detection at reflectances well below actual. In spectral mixture analysis and physical retrievals, the signal is contaminated or inaccessible.

SUN-ATMOSPHERE-EARTH RADIATION INTERACTIONS

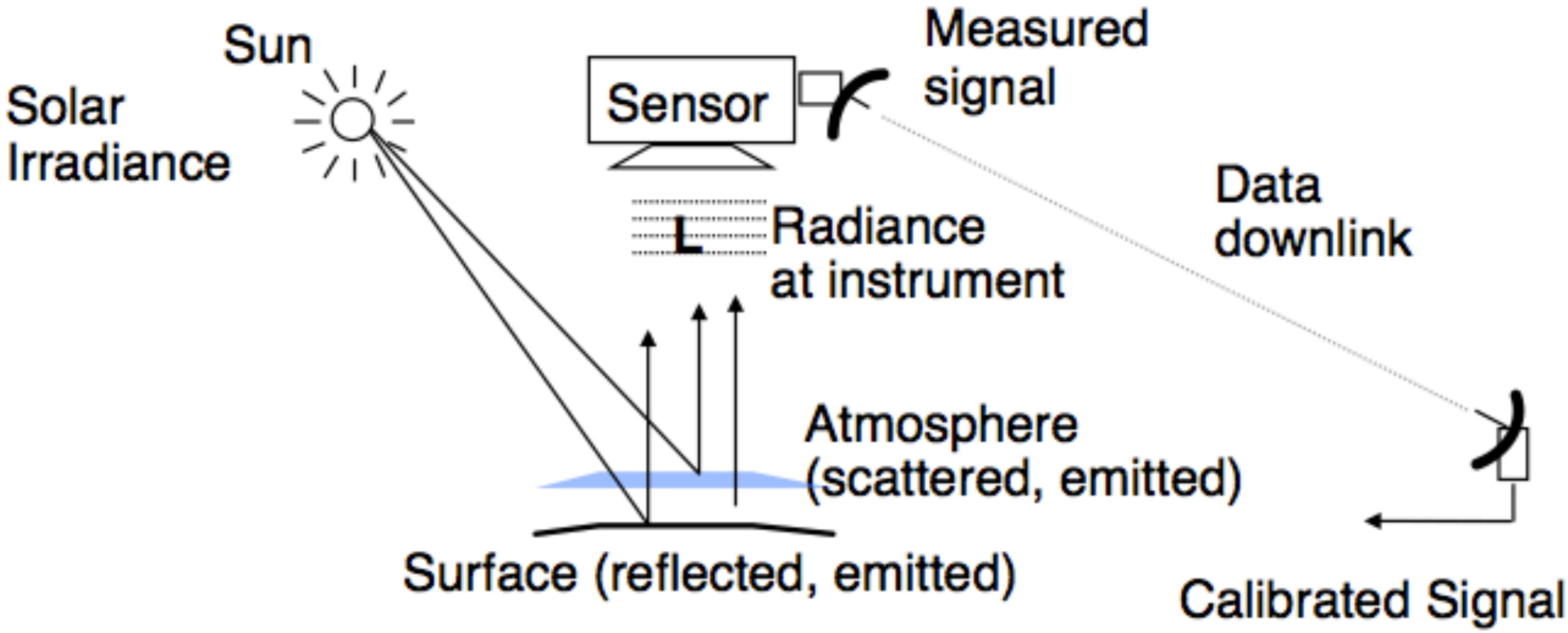
Available Signal in the Optical Spectrum



Transmittance of the Atmosphere



The Available Signal and Approach



Energy is emitted by the Sun as well as planet sources

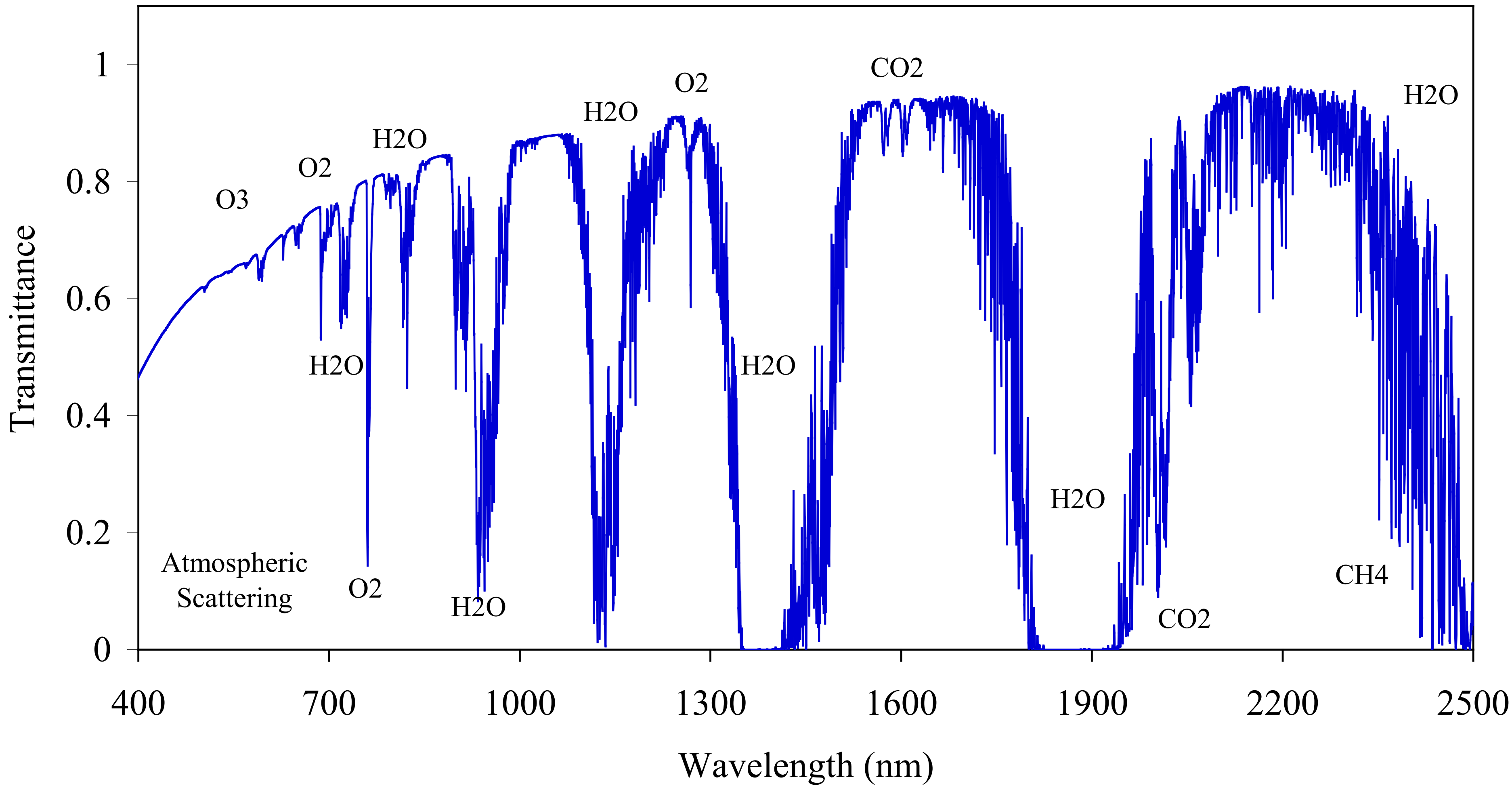
The energy is transmitted and scattered by the atmosphere and reflected from the surface

The imaging sensor responds to the energy (L) within a field-of-view and spectral range

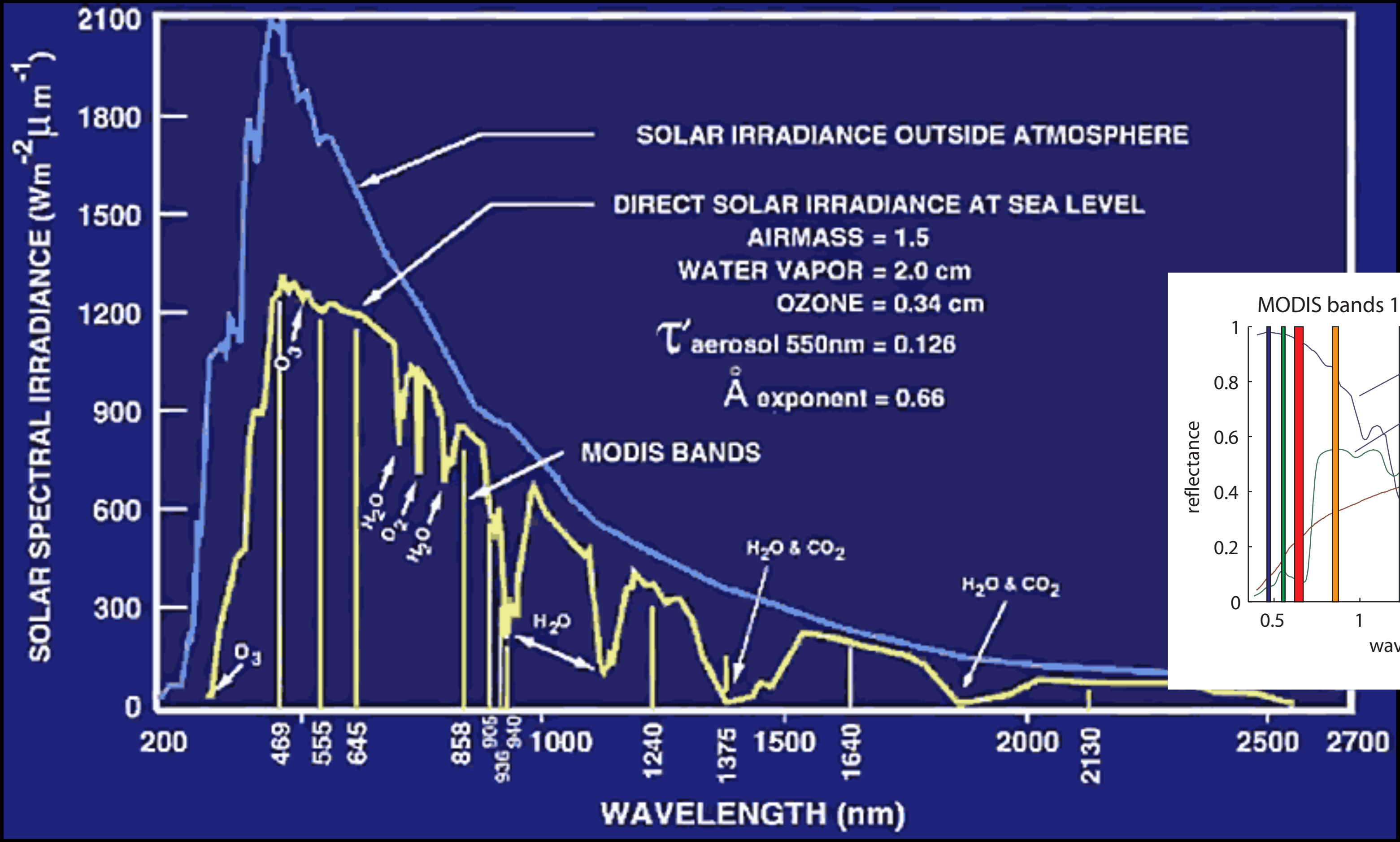
Sensor signal is digitized and relayed to the ground and recorded

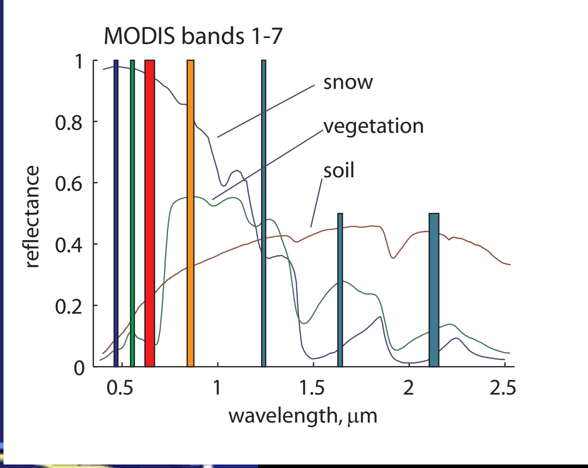
The signal is calibrated, processed, and analyzed to answer the questions of interest

Transmittance of the Atmosphere



MODIS spectral irradiance





SNOW OPTICAL PROPERTIES

Mountain Snow

Snow albedo The total reflectivity of snow to all incoming sunlight

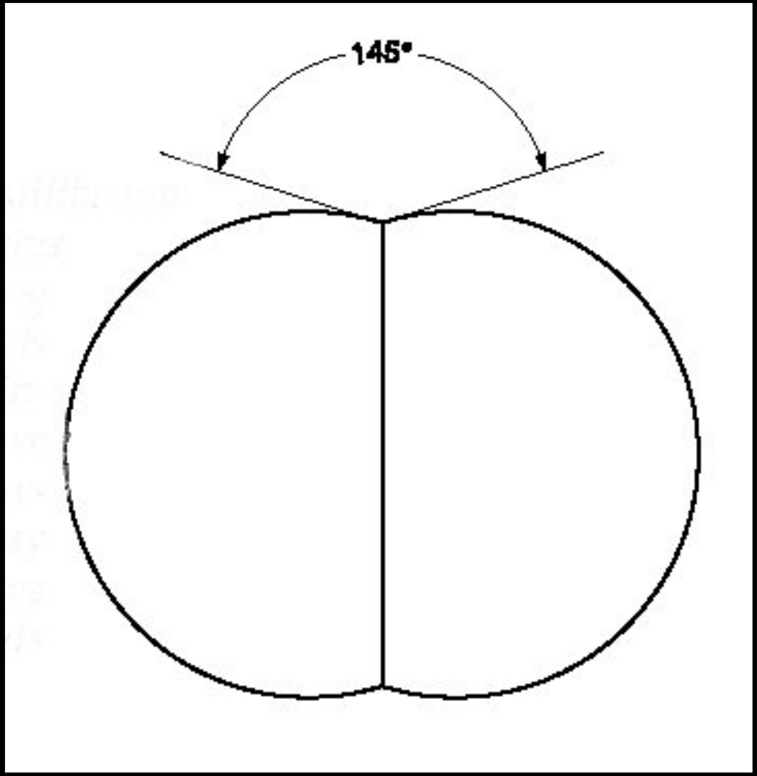
Snow spectral albedo The total reflectivity of snow to all incoming sunlight in a particular wavelength (color) range

HDRF Hemispherical-directional reflectance factor – this is how the angular distribution of snow-reflected sunlight varies relative to a perfectly diffuse surface

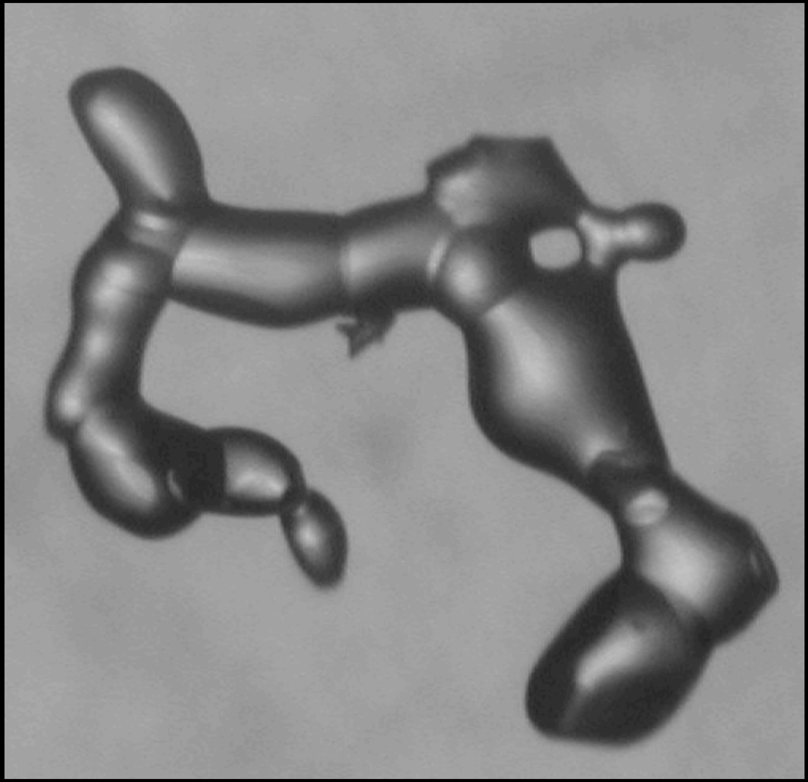
Mountain Snow

Snow metamorphism the evolution of snow particle shape and dimensions after falling from the sky

Dry Snow Metamorphism

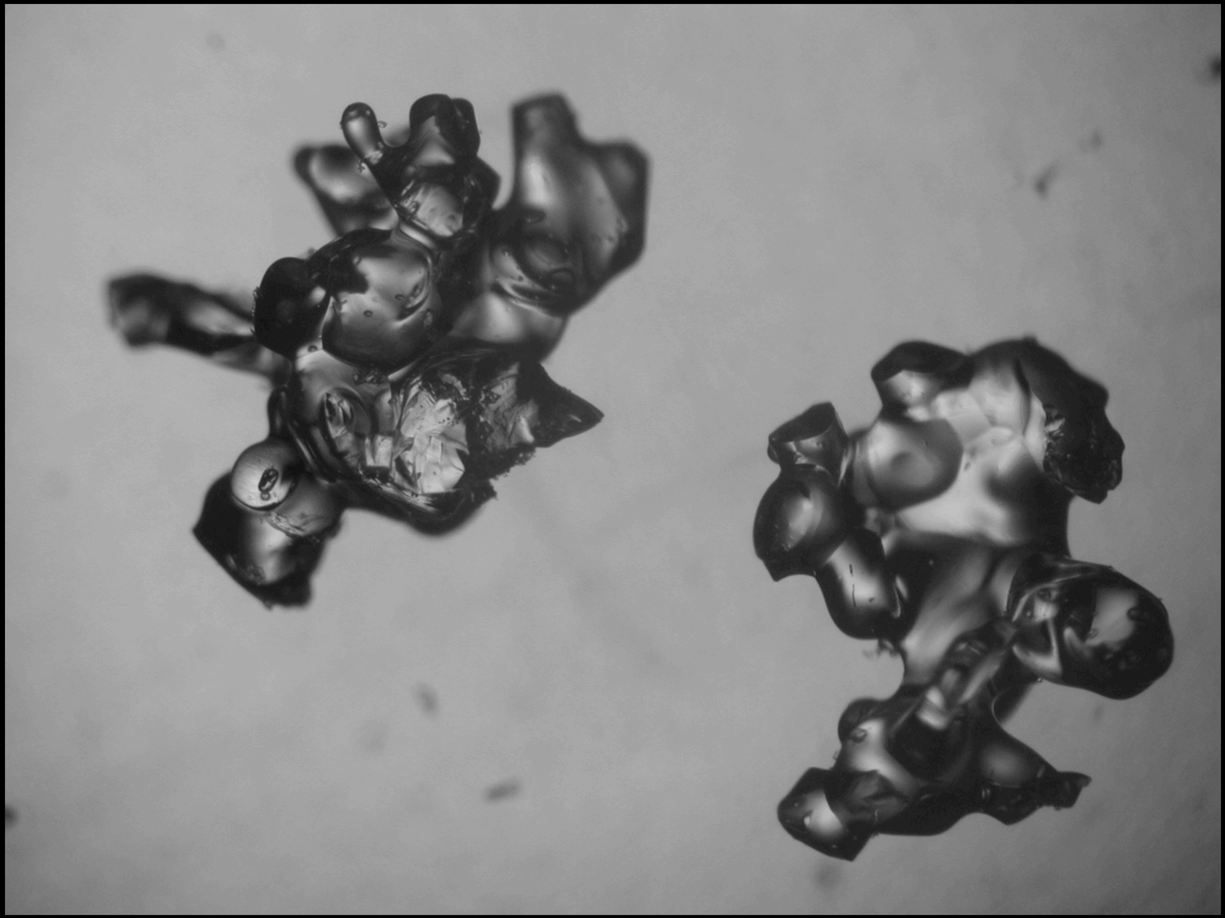


From Colbeck (CRREL 1997)



20 day old dry snow – Mammoth, CA

Wet Snow Metamorphism



Melt-freeze grains

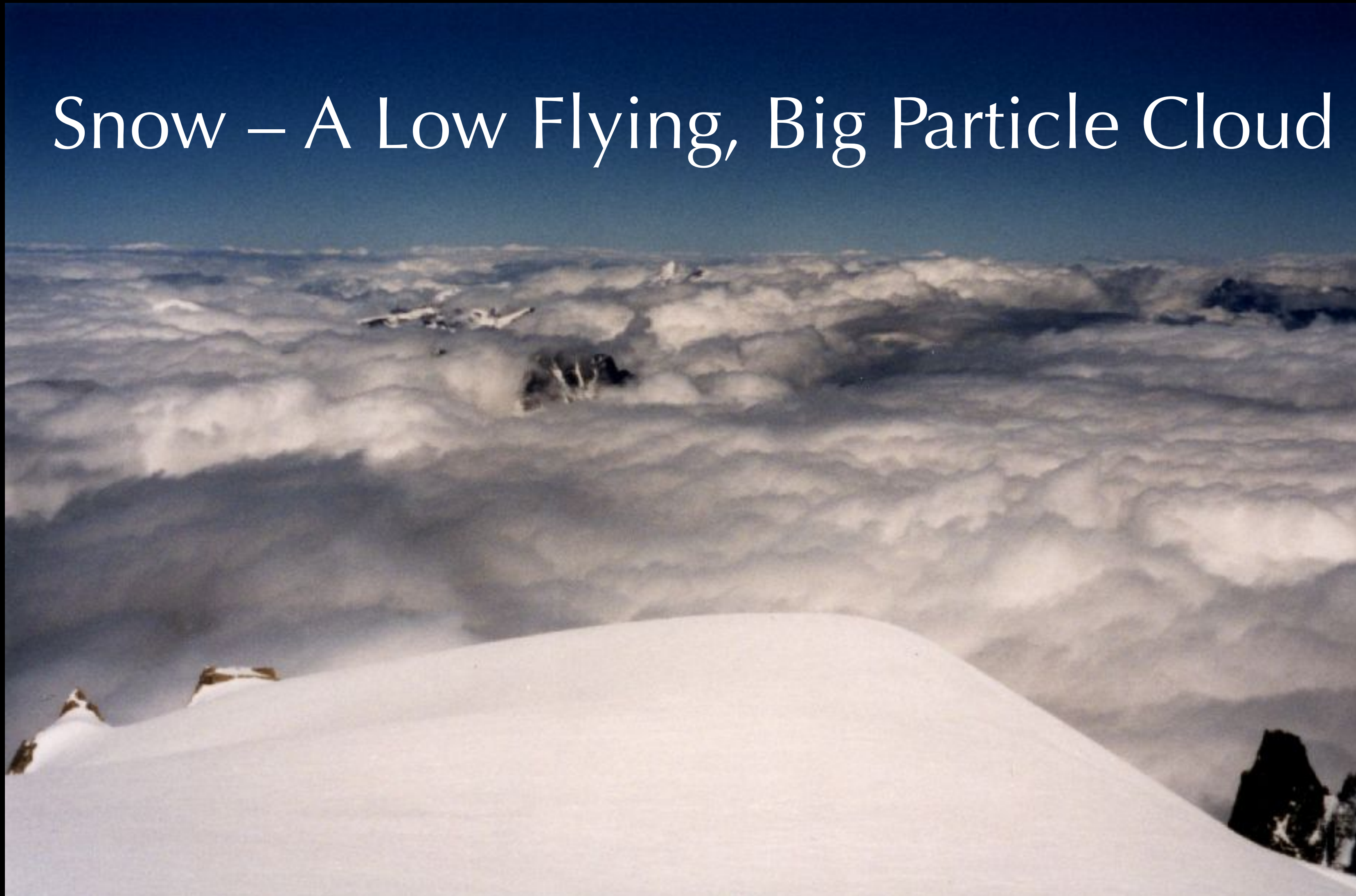
Mammoth, CA

Winter, 2001

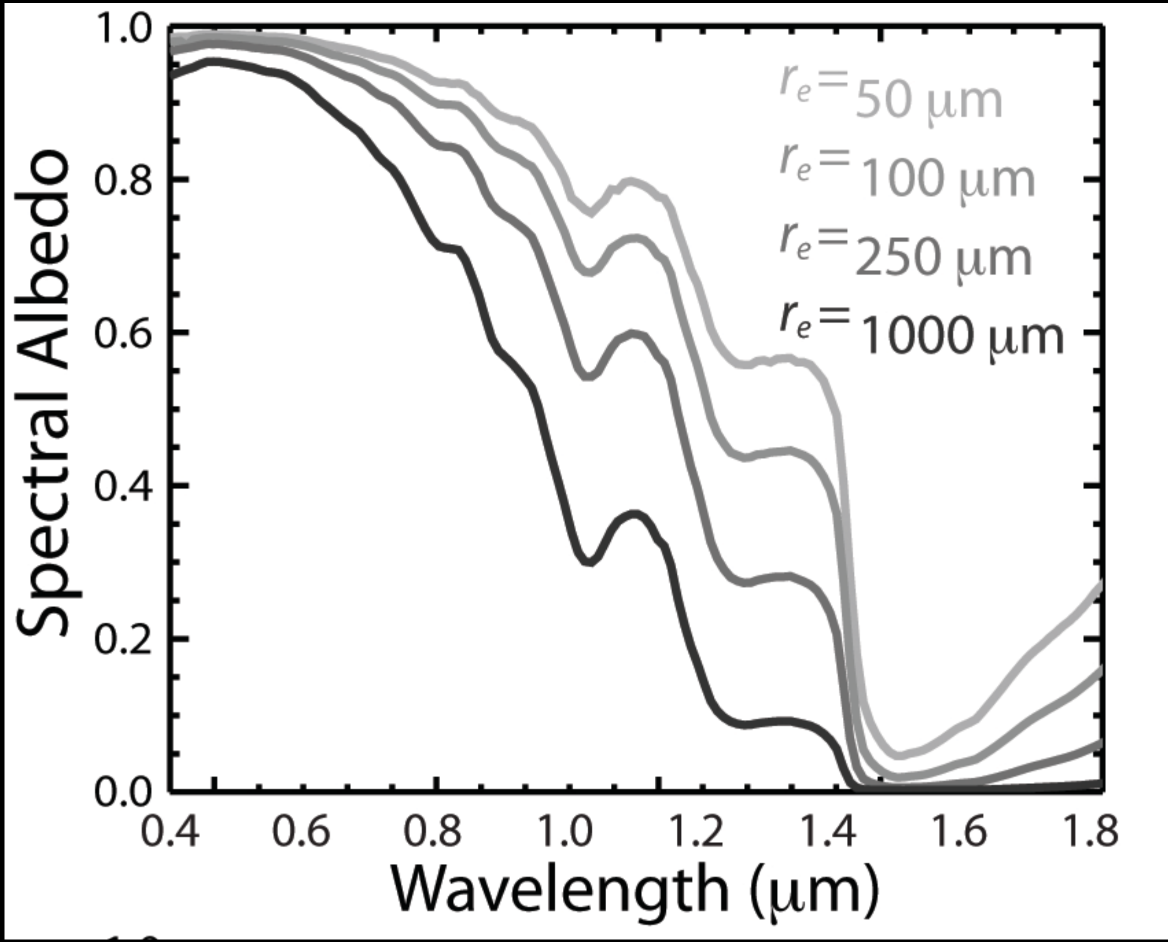
Snow Metamorphism

- Snow metamorphism has monotonic decrease in the ratio of surface area to volume
- Absorbing path length (grain size) has monotonic increase
- Metamorphism is more rapid at higher temperatures
- Metamorphism is even more rapid in the presence of liquid water

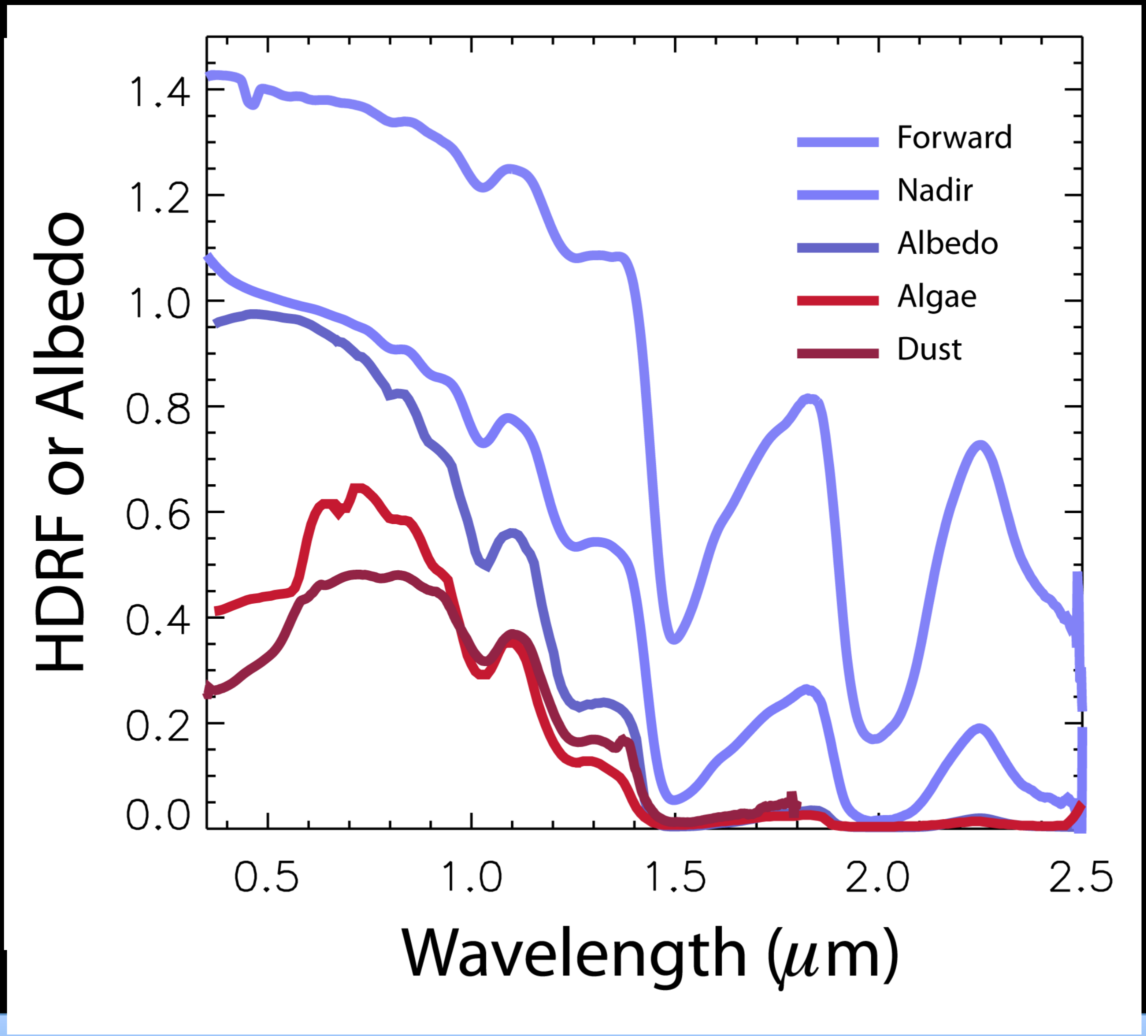
Snow – A Low Flying, Big Particle Cloud



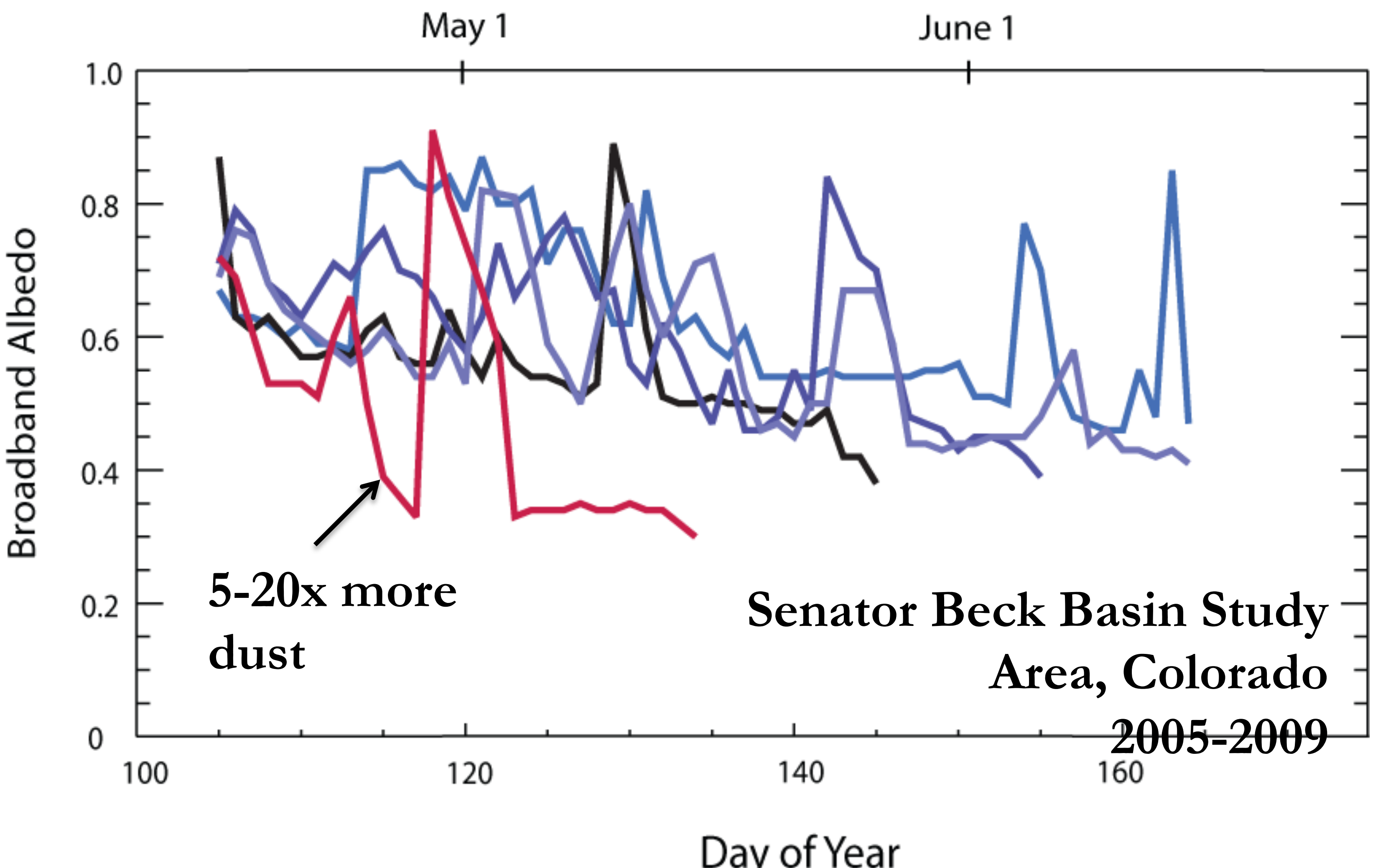
Snow Reflectance



The Earth's Most Colorful Surface

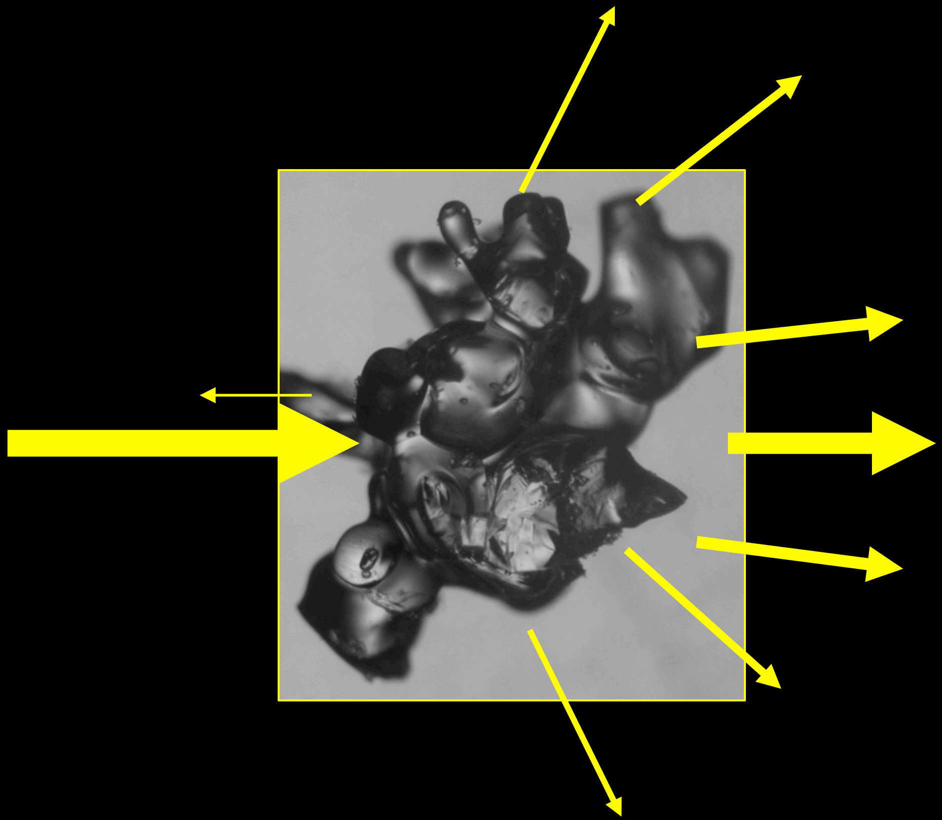


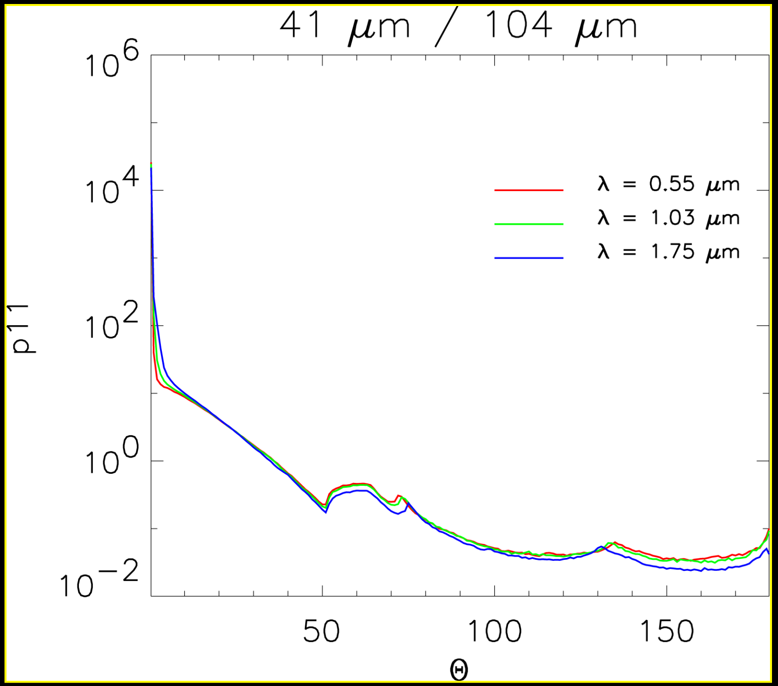
Albedo



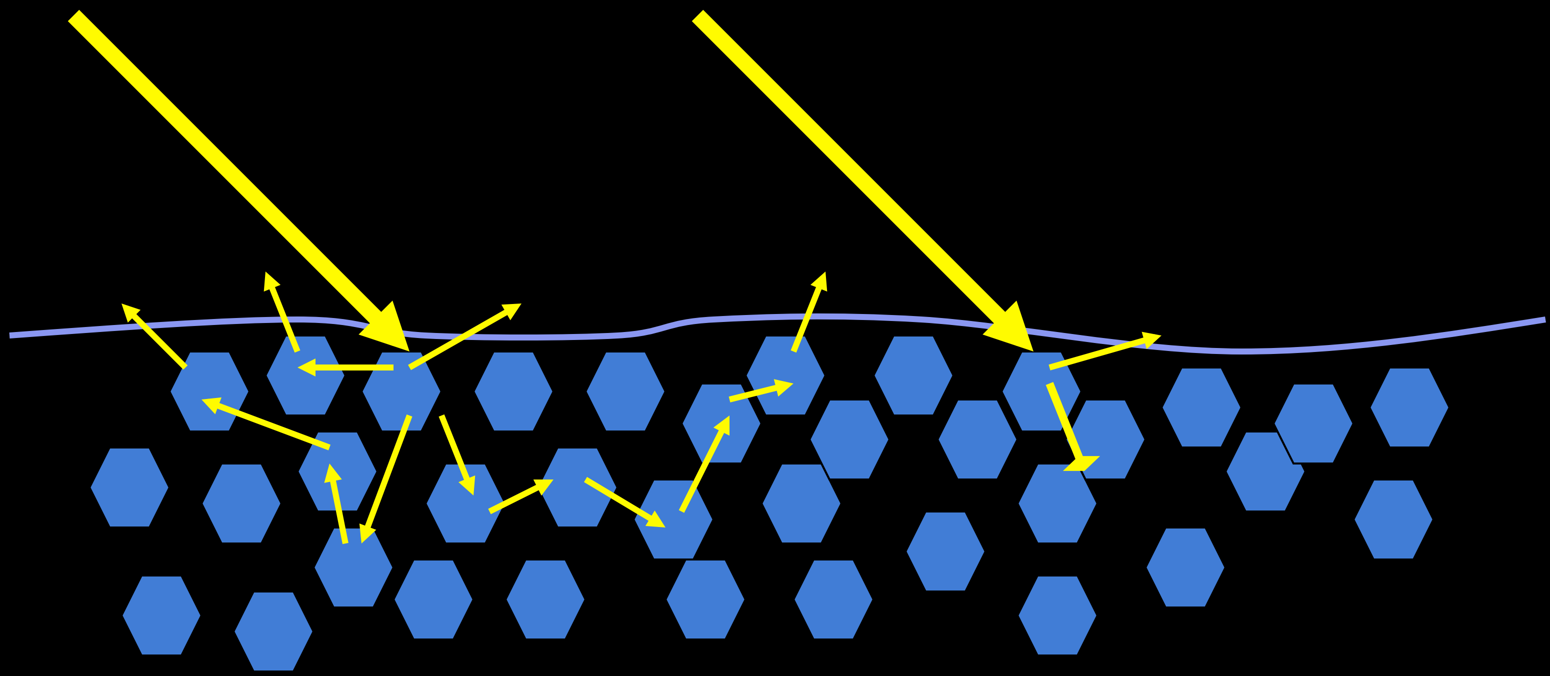
Skiles et al **2012**

Single Scattering





Multiple Scattering

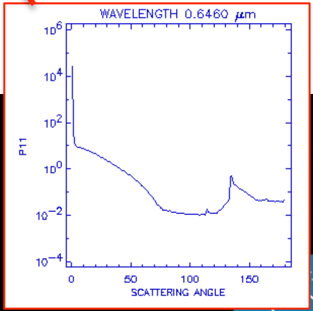


Radiative Transfer Equation

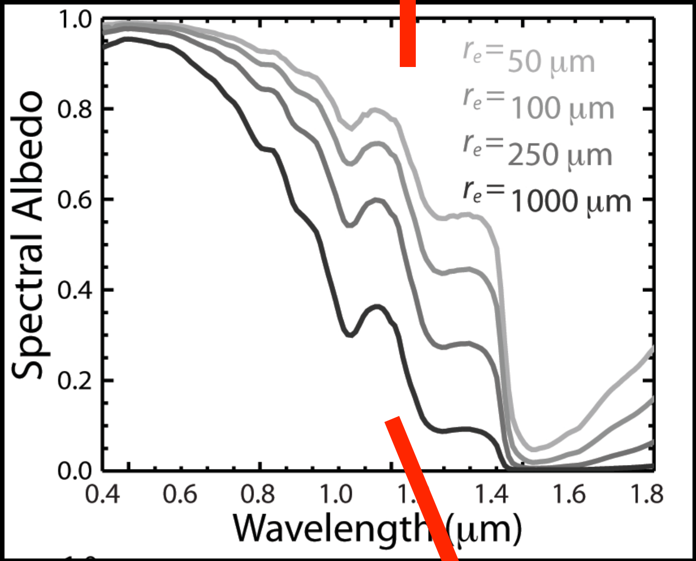
Change in radiation intensity with change in optical depth through medium

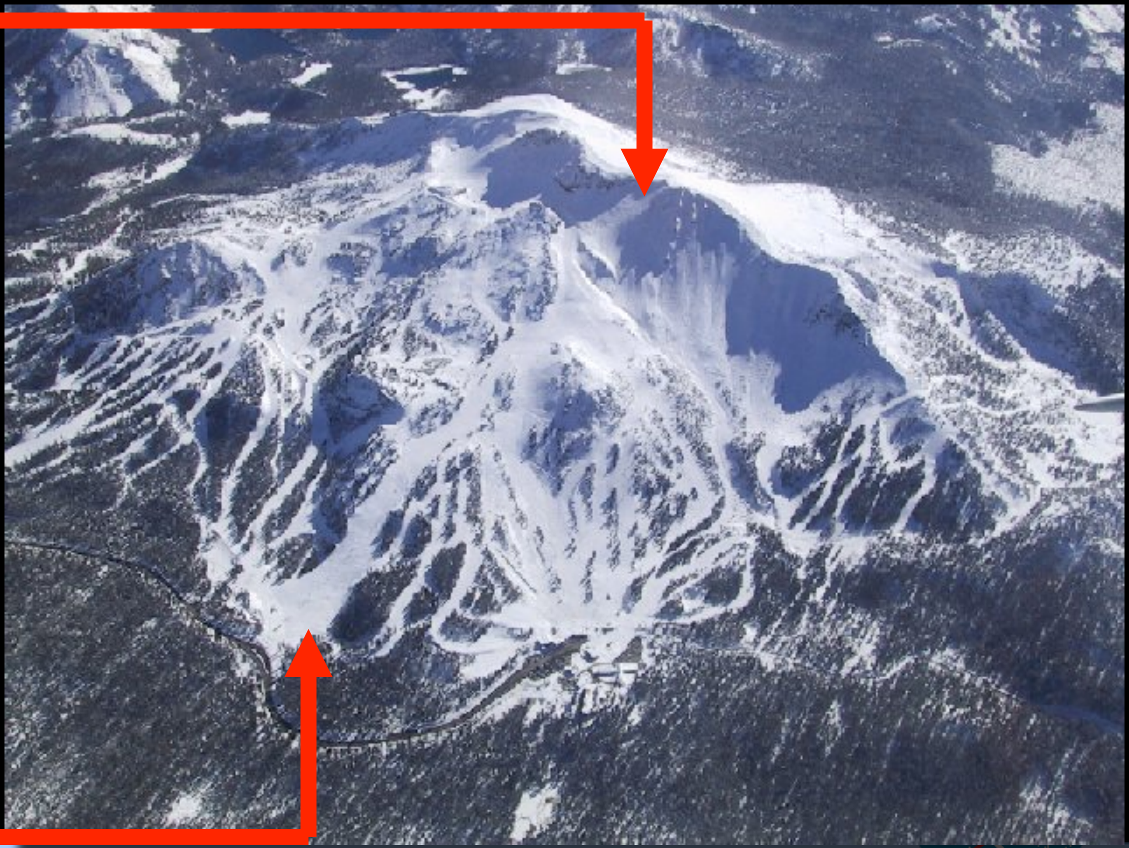
$$\mu\frac{dI(\tau,\mu,\phi)}{d\tau} = \overbrace{I(\tau,\mu,\phi)}^{\textbf{Beam}} - \overbrace{[1-\omega(\tau)]B(T(\tau))}^{\textbf{Emission}} - \overbrace{\frac{\omega(\tau)}{4\pi}\int_0^{2\pi}d\phi'\int_{-1}^{1}p(\tau,\mu,\phi;\mu',\phi')I(\tau,\mu',\phi')d\mu'}^{\textbf{Scattering}}$$

$$\underbrace{-\frac{\omega(\tau)I^{inc}}{4\pi}p(\tau,\mu,\phi;-\mu_o,\phi_o)e^{-\tau/\mu_o}}_{\textbf{Beam Scattered}}$$

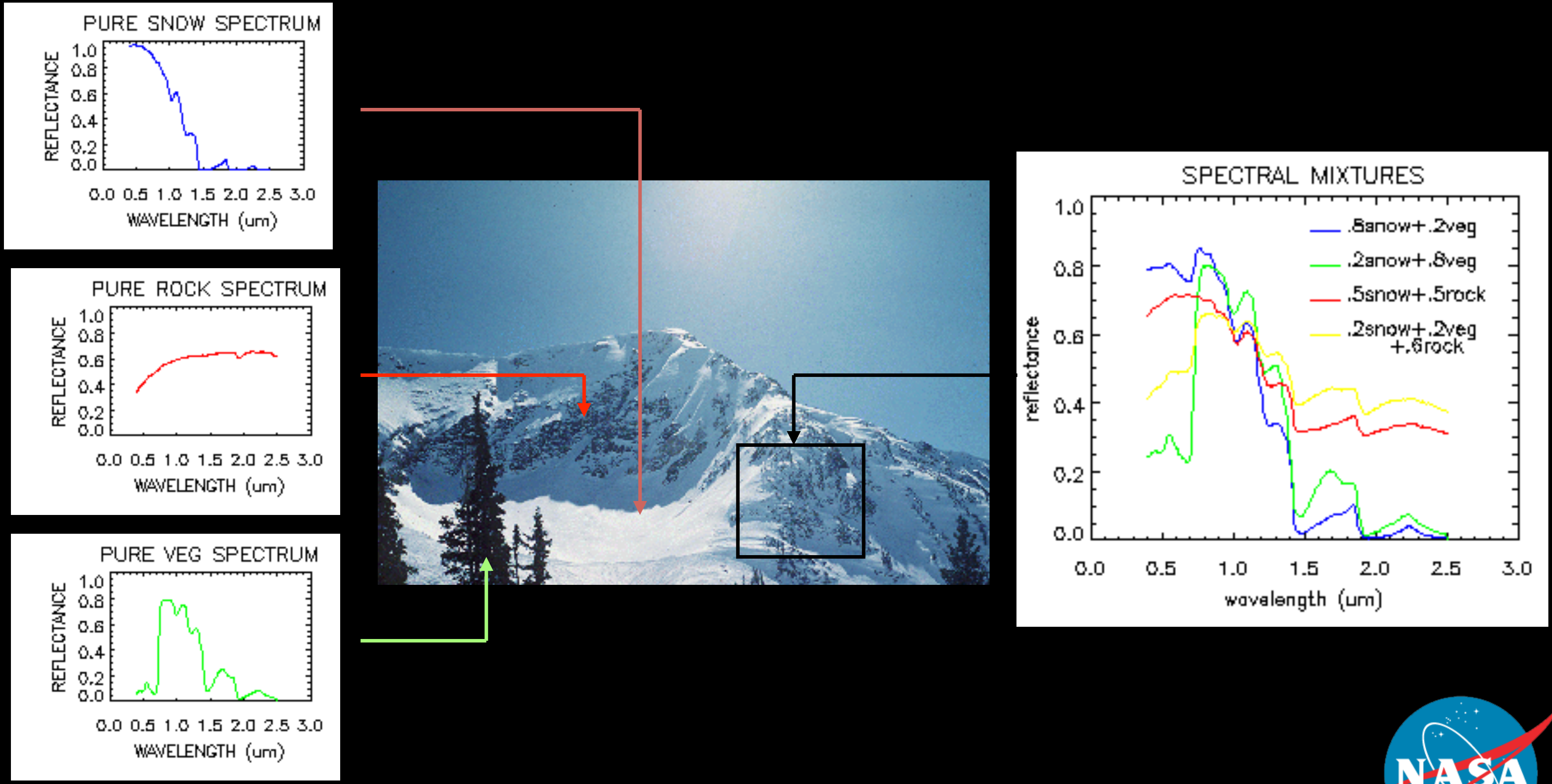


Spectral Gradients



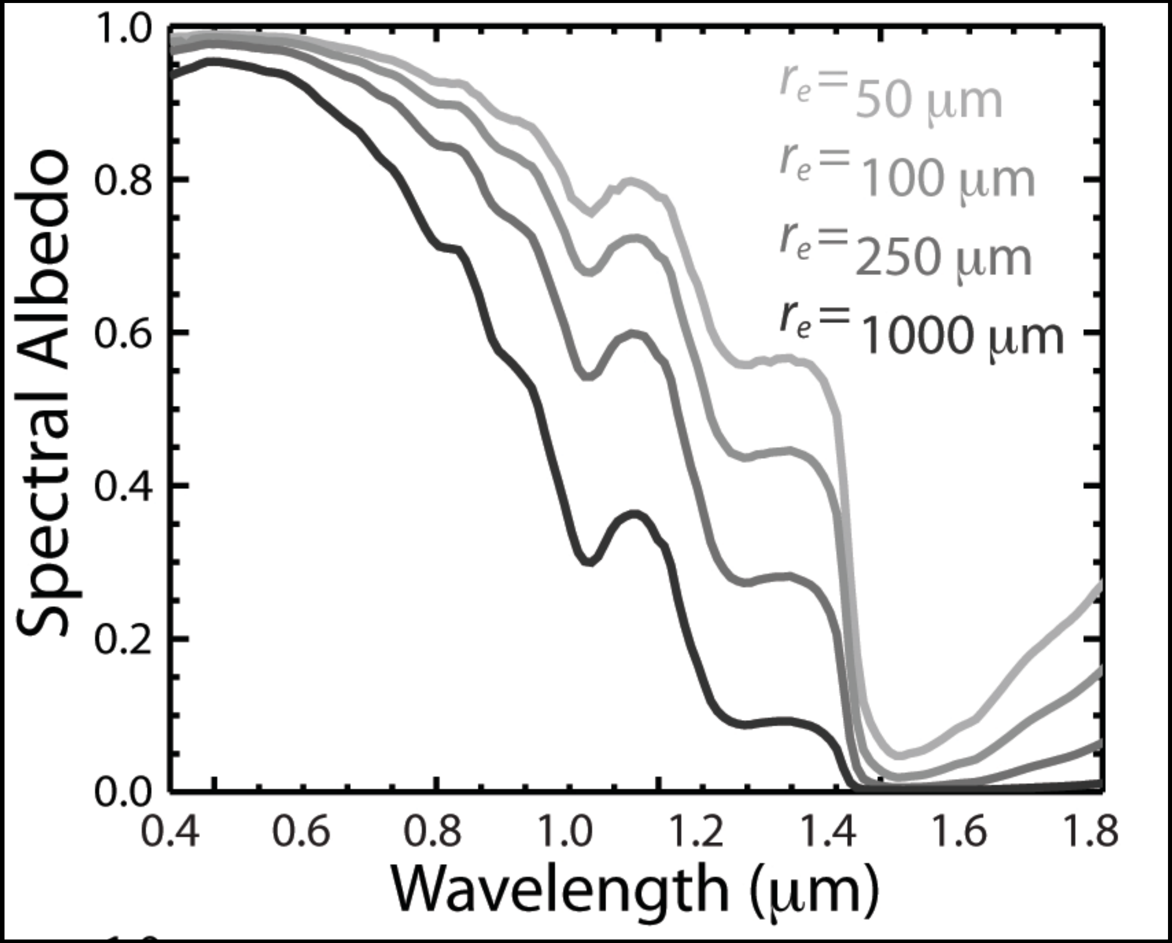


Spectral Mixing

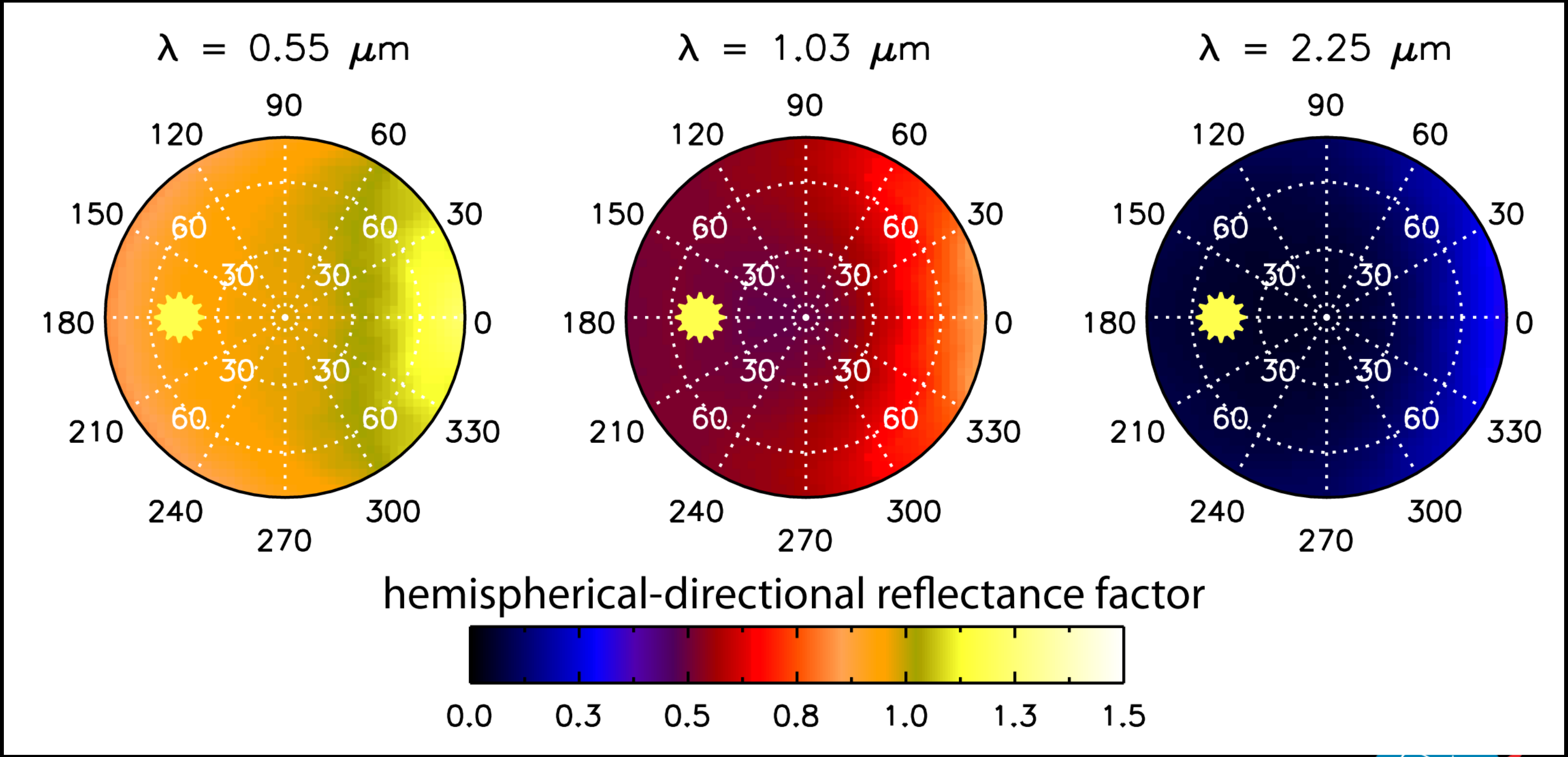


SNOW REFLECTANCE

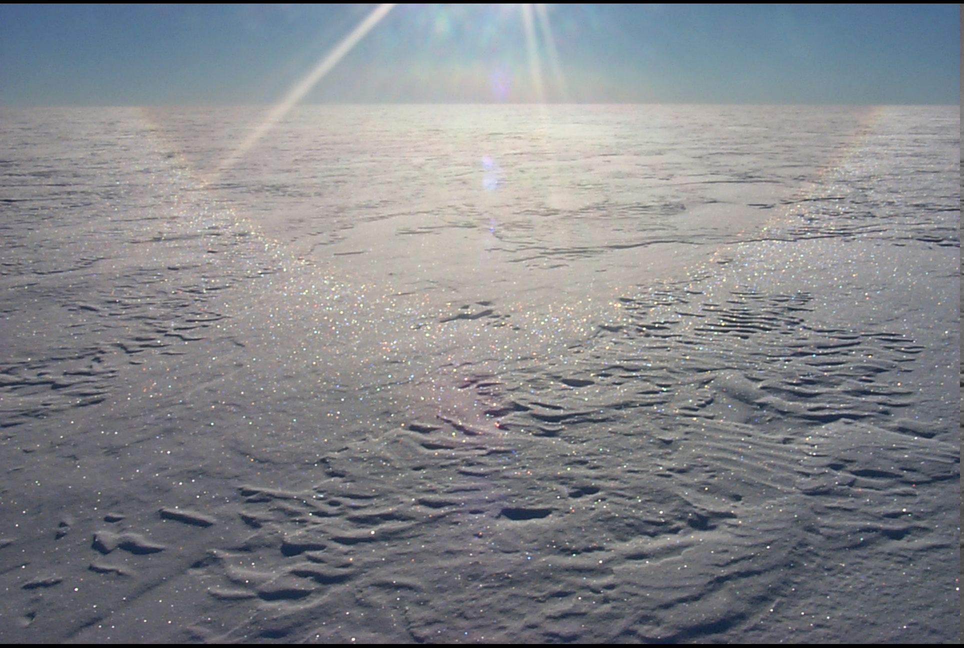
Snow Spectral Albedo



Snow Directional Reflectance – that is, what a satellite sees from different angles



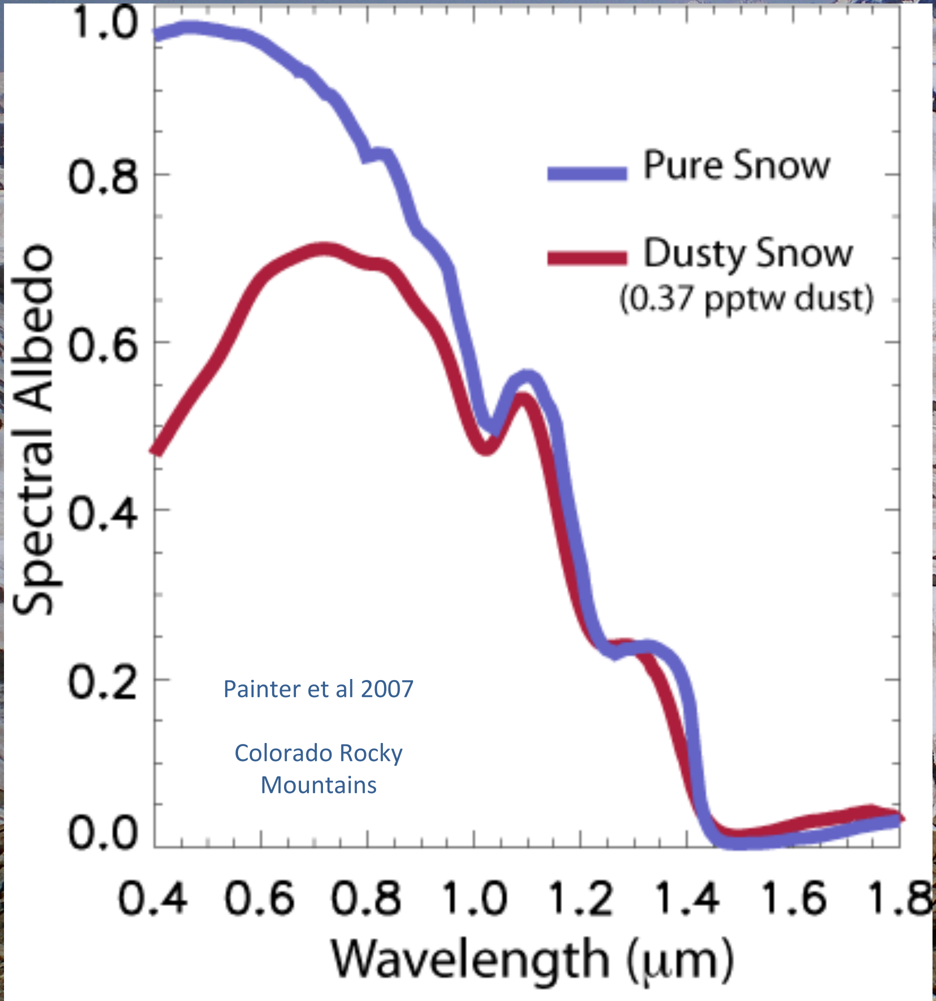
Snow Directional Reflectance

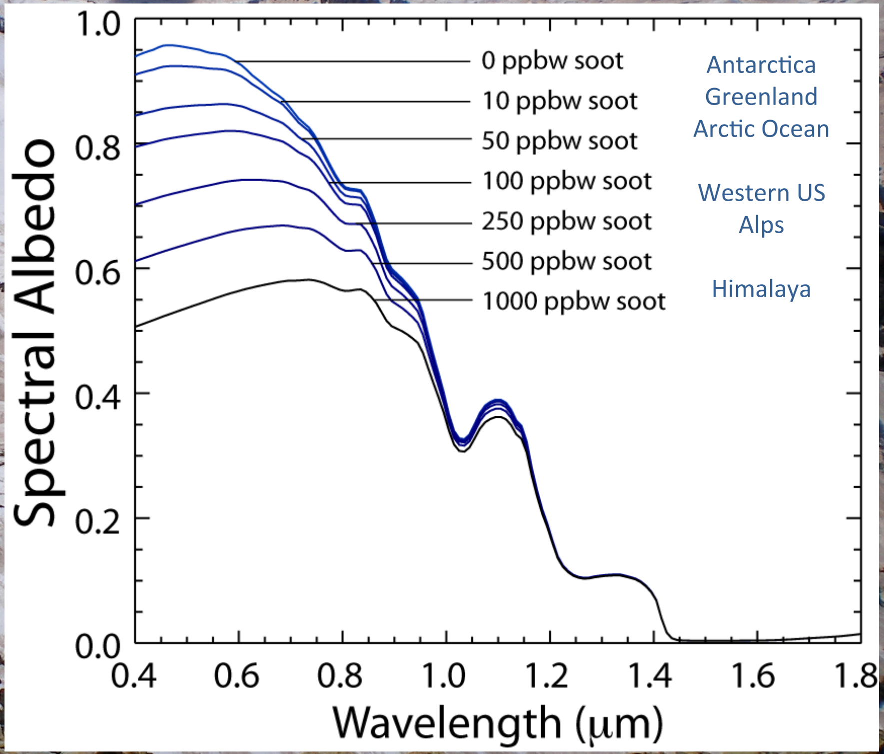


Vegetation Directional Reflectance

rlin Quad

Effect of dust and black carbon on snow reflectance





Next Week

- The MODIS Snow Covered Area and Grain Size (MODSCAG) model and products
- The mixture of snow directional reflectances with vegetation and soil reflectances
- The impacts of view geometry
- The improvements to hydrologic modeling and our understanding of climate change